THE LOW LEVEL RADIATION CAMPAIGN

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Radiation and reason:

The impact of science on a culture of confusion

A summary and brief explanation of the origins, history and current dialogue concerning evidence that there are grounds for an urgent re-evaluation of the link between ionising radiation and health problems, particularly in children and young people.

A preliminary report for the charity Children with Cancer UK

"There is clear evidence that releasing some forms of radioactivity to the environment has unexpectedly large health consequences although the doses involved appear to be minuscule. Examination of the concept of "radiation dose" reveals that its administrative convenience and apparent precision mask a complex and poorly understood area of science. This demands a thorough forensic review which should be regarded as an urgent priority since a number of policy areas including waste management, the management of contaminated land, and nuclear weapons and power generation are likely to be significantly affected."

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1 Introduction

This report is intended to inform a lay audience about the long-running controversy over the health effects of ionising radiation (IR). There are two central concerns. One is to dispel the frequently repeated assertion that public anxiety about the health impact of radioactivity in the environment is irrational. The allegation of irrationality depends on the fact that, according to conventional assessments, the radiation doses human beings receive from industrial or military discharges are thousands of times too small to have any discernible effect on rates of disease. The report's thrust is to explain the scientific concepts and assumptions underlying those assessments and to unravel anomalies, the greatest of which relate to uranium. The second central concern is to consider the controversy as an example of a scientific revolution or paradigm shift, which is a sociological phenomenon. Resources do not allow exploration of the sociological literature on this topic and it will not be explicitly discussed in the report. A substantial section, however, lays out much of the authors' personal experience of how government, industry, regulators and advisory bodies manage dialogues and sideline the concerns of Non-Government Organisations — the kind of activity that Thomas Kuhn described as the professions "evad(ing) anomalies that subvert the existing tradition of scientific practice".[1]

The report will examine the origins of the controversy and how it has been perpetuated. It will not attempt any compendium of evidence from physics, biology or epidemiology but will address those topics to the extent that they illuminate the controversy and the kinds of argument that are used to deflect attention and allay concern. In the interests of increasing public understanding it will explain the central concepts in accessible language and will tend towards citing scientific literature that the reader can obtain without financial cost. Technical language will be avoided as far as possible and will be explained where it cannot be avoided. Since the controversy has been perpetuated by imprecise use of terminology, care will be taken to explain technical terms. Underlined text denotes a term that is defined in the glossary.

The fundamental conclusion of this report is that when the evidence is rationally assessed it appears that the health impacts, especially in the more radio-sensitive young, have been consistently and routinely underestimated. This results from inappropriate modelling of risk using the Linear No-Threshold hypothesis (LNT), which arose from political and military imperatives at a time when the biological behaviours of man-made radioactive elements were unknown and the structure of DNA had yet to be discovered. There are large uncertainties about microdosimetry, particularly as it applies to uranium and tritium which are major components of the environmental radioactivity attributable to human enterprise. The authors believe that the evidence summarised here reveals a dissonance between the averaging implicit in LNT and the binary realities of radiation hits, DNA damage, repairs, and mutation. The solution is for LNT to be replaced with a system based on ionisation density in vulnerable targets. There is a clear need for research to develop such a system and, in the interim, an equally clear need for regulation to continue seamlessly. The European Committee on Radiation Risk has developed weighting factors to modify ICRP's risk estimates for exposures which involve high ionisation densities. We recommend that this interim approach should be followed. Urgent, forensic and expert review is needed, and this should extend to investigating the degree to which the environment is contaminated with anthropogenic uranium and the degree to which natural background radiation enhances the genotoxicity of uranium.

[1] "The Structure of Scientific Revolutions": T.S. Kuhn. Univ. of Chicago Press 1970 ISBN 0-226-45804-0

1.1 A note on dose

The Introduction above notes the malign role of imprecise terminology and commits the authors to avoiding technical language. One term that demands particular attention is "dose", which has been impossible to avoid because it pervades the literature on radiation and health, both scientific and populist. This report's core message is that the conventional concept of dose in this context is problematic, since it is defined in terms of the SI unit of work, energy and heat (the joule) acting upon kilogrammes of water. Authoritative sources will be cited to establish that this macroscopic averaging of energy breaks down at the microscopic level of cells in body tissue and becomes increasingly meaningless at the still smaller scales of chromosomes, DNA and their component molecules and atoms. This is a matter of quantum mechanics, which is concerned with the behaviour of the same subatomic particles that are, in fact, radiation.

It must be said that the conventional radiation risk agencies recognise that the average dose concept is inadequate and this has resulted in a bewildering array of terminology and adjustment factors but this report will not use them because they do not drill down to the quantum level and are therefore unnecessary to understanding the more fundamental issues.

Two items of terminology need to be defined because they pervade the literature. These are the gray and the sievert, which are both dose units. The gray (abbreviated to *Gy*) is the dose unit defined in joules per kilogramme, as stated above. The sievert (Sv) is the same as the gray but multiplied by a factor intended to express the different amounts of biological damage that different types of radiation do to human tissues — a concept known as Relative Biological Effectiveness (RBE). The sievert is the unit most commonly used to quantify doses. It appears as millisieverts (mSv) representing thousandths of a sievert, or as microSv, representing millionths of a sievert.

The sievert is subjective and is constantly under review by international radiation protection agencies. The relevant issue for the purpose of this report is that, at present, the widest divergence in RBE is a factor of 20. Theoretical considerations and real-world evidence suggest strongly that, for internal uranium, a factor of at least 10,000 is realistic.

2 Summary, conclusions and recommendations

Ionising radiation and its impact on health, particularly in the young and unborn, has been a source of controversy since its discovery. The controversy has been perpetuated by political, military and economic imperatives associated with the continued use of nuclear power and weapons which results in ambiguity and misunderstanding, not to say deliberate obfuscation.

There are 60+ studies which identify elevated numbers of cases of harm in those living close to nuclear installations which should not be theoretically possible if the official interpretations are accurate.

The ‘Windscale – Nuclear Laundry’ TV programme in 1983 identified a cluster of leukaemia among children living in the village of Seascale, close to the Windscale nuclear reprocessing plant, prompting the government to establish an investigation leading to the forming of the Committee on Medical Aspects of Radiation in the Environment (CoMARE).

In addition to the eight, inconclusive reports on childhood leukaemia and other childhood cancers produced by CoMARE between 1986 and 2016, further studies conducted by radiation protection bodies in other countries produced literature which allowed Baker and Hoel, epidemiologists from the University of South Carolina, to produce a meta-analysis of results covering 136 nuclear sites in nine countries which found elevated rates on ‘near site’ leukaemias in the majority of studies.

Other studies contradicted these findings: Cook-Mozaffari's analysis of leukaemia mortality across England and Wales showed a 15% increase in cancer in young people living in districts close to nuclear facilities.

The international implications of these findings, if verified, for energy and defence policies would be significant. This has led to attempts to avoid such implications by demonstrating that elevated leukaemia rates are present in areas where no nuclear facilities exist, where they were planned to be built but where the plans were not realized, that elevated levels existed before plants were built or that the statistical insignificance of the numbers militated against a link between ionizing radiation and leukaemia nullified the findings. Other papers claiming to demonstrate that leukaemia cannot be attributed to ionising radiation, such as that published recently by Dr Frank Boulton, rely on the acceptance of the life span studies (LSS) despite their silence on the impact of internal radiation.

Confounding factors were shown to exist to counter all attempts to explain the precision of these counter arguments: the argument that high incidences of leukaemia exist in areas where no nuclear plants exist does not take into account historic high levels of nuclear weapons test fallout and other confounding factors such as proximity to other nuclear facilities.

In 2008, the debate was re-ignited by the publication of the KiKK report which identified a 60% increase in cancers and a 120% increase in leukaemia in children under 5 years living within 5kms of nuclear plant in Germany, with results falling off monotonically out to 50 km, suggesting that it was truly related to the NPPs and not to chance or other factors.

According to a 2012 EU workshop report, KiKK was emulated in several other countries and it was noted that even when the findings were not statistically significant, they, like KiKK, showed an elevated risk of childhood leukaemia in 0 - 4 year olds living within 5 km of a NPP. The continuous slope to 50 km was not mentioned.

The debate around statistical significance has led to the recommendation that observed leukaemia increases should be reported while acknowledging, where appropriate, a 5% possibility that they could have occurred by chance. Eight hundred and fifty academics have endorsed the same principle on public policy grounds.

Nuclear fission of heavy elements was discovered in 1938 and the race to develop nuclear weapons began: primitive exposure limits developed for radium were extended to plutonium, although nuclear fission produced other novel elements presenting different but unknown health hazards.

Concern over the hazards of alpha ray-emitting substances – intensely damaging to tissue but only over very short distances - such as radium, uranium and plutonium led to the setting up of two committees inside the framework of the US National Committee on Radiation Protection (NCRP) but soon the two issues under review – internal and external radiation – were conflated: the concept of assessing health effects on the basis of averaged external dose had taken root.

'Safe' doses of ionizing radiation and their presumed associated health impacts are largely based on the assessed dose received by the Hiroshima and Nagasaki nuclear victims as a result of the bombs dropped on these two cities in 1945.

The controversy surrounding the accuracy of the interpretation of the data centres on the absence of data for internal damage caused mainly by alpha-emitters such as uranium and plutonium which are released as a result of nuclear activity such as weapons testing or power generation.

These assessed doses, based on survivors' recollections of how far they were from the detonations, form the basis of the recommendations used by the International Commission on Radiological Protection (ICRP) and hence for the official authorizations and dose limits for exposure to ionizing radiation.

The data from the victims' (known as hibakushas) recollections and the on-going monitoring of their health is known as the Life Span Study (LSS): the perceived shortcomings of the LSS and its conclusions in terms of health impacts from ionizing radiation is pivotal to the controversy over the true extent of health damage caused by exposure to ionizing radiation insofar as there is concern that the LSS and the resulting ICRP recommendations may not incorporate all the necessary information for protecting public health.

In 1955 David Hewitt, a colleague of the epidemiologist Dr. Alice Stewart at Oxford University's Social Medicine Department published a paper on child leukaemia mortality, showing rates approximately doubled between 1930 and 1953.

Stewart set up the Oxford Survey of Child Cancer (OSCC), a long-running case control study of prenatal influences based on interviewing two groups of mothers which showed that if a pregnant woman had an abdominal X-ray the chance that the child would die from cancer or leukaemia by its 15th birthday increased by 40%.

The downward trend in the incidence of first day neonatal mortality in the USA was interrupted by the beginning of above-ground nuclear weapons testing in 1951, resuming its declining trend in 1963 when the partial test ban outlawed atmospheric testing. Similar trends were experienced after the tragic Chernobyl accident.

High voltage power lines cause airborne particles to be concentrated nearby. It has been known for a long time that this is because the electric current causes electrostatic effects.

In 2005, it was discovered that rates of childhood leukaemia were higher in children who lived within 600 metres of power lines.

A recent open access review of studies of congenital malformation in Europe and the near East after Chernobyl shows the effects were many times greater than predicted by ICRP risk factors.

WHO reported in relation to the Chernobyl disaster, that: "There has been a slow but steady increase in congenital malformations recorded in both high and low contamination areas, but the increase does not show a dose-response pattern. […] In fact, there were statistically significantly less congenital abnormalities in the high contamination areas compared with low contamination areas ..." thus giving weight to the conclusion that official interpretations of the dose/risk relationship are fundamentally misunderstood and potentially flawed.

The range of differences in damage caused to human tissue by different types of ionising radiation is represented by "Relative Biological Effectiveness" (see Para.10.5) The widest divergence in RBE currently acknowledged is a factor of 20. Theoretical considerations and real-world evidence (e.g. as summarised in Part 6) suggest strongly that, for damage resulting from inhaled or ingested uranium, a factor of at least 10,000 is realistic.

Recommendations

It is recommended that a more comprehensive assessment of the studies which indicate harm from exposure to ionising radiation at routine levels are identified and funded as a matter of urgency and to develop from such a study a defined work programme designed to reduce uncertainty.

As discussed in section 7.2, uranium is known to bind to DNA in vitro and this report outlines how a combination of soluble uranium and natural background radiation places a mutational mechanism on the DNA molecule. However an exhaustive literature search has failed to quantify the extent of uranium/DNA binding in living systems. A plant germination experiment is in progress to test whether a combination of soluble uranium and external gamma rays alters rates of genetic mutation, controlled against samples not treated with uranium. It is recommended that parties interested in radiation protection concern themselves with the results of this programme and the health implications and that

encouragement and incentives are given for the development of further experiments designed to increase knowledge of the DNA binding hypothesis.

The report has also discussed evidence of risks associated with particles suggesting a very large underestimate. It should be borne in mind that hundreds of tons of uranium were vaporised and fissioned in the pre-1964 weapons tests, that UNSCEAR reports show substantial amounts of particulate material released from nuclear power stations around the world,[2] that the Chernobyl explosion and fire released an unreported proportion of the 200+ tons of uranium in reactor 4, and that the Fukushima disaster has created a similar situation. The failure on the part of official agencies to monitor particulates in the environment is deplorable and it is recommended that an independent Uranium Particles in Air and the Environment (UPAE) programme be established to use relatively affordable techniques to complement official RIFE reports by monitoring and sampling and that agencies involved in the ionising radiation and health issue combine resources to establish such a programme with appropriate membership and funding.

The European Committee on Radiation Risk has developed weighting factors to modify ICRP's risk estimates for the exposures which involve high ionisation densities. We recommend that this interim approach should be followed.

Secondary Photoelectron Effect and heavy metal toxicity public health implications should be investigated through the funding of appropriate projects.

Research into DNA binding in vivo should be encouraged and funded.

It is recommended that CwC UK funds analysis of childhood leukaemia by cohort year of birth of mother.

It is recommended that the enhancing effect of the presence of electromagnetic fields is the subject of thorough investigation.

It is recommended that CwC UK's grant calls should prioritise projects which directly support a comprehensive understanding of the impact of ionising radiation on human health, with an emphasis on the health of children.

It is recommended that the government, regulators, advisory bodies, trades unions and the civil and military nuclear industries should be informed of such a research programme and asked to support it and to contribute to it as appropriate.

It is recommended that approaches are made to agencies responsible for authorising levels of exposure to ionising radiation to encourage them to engage with this debate in a spirit of co-operation and in the interests of advancing knowledge and understanding of the DNA binding hypothesis and other areas of divergent opinion as expressed in this report.

Follow on work: there is a need to make a more comprehensive assessment of the studies which indicate harm from exposure to ionising radiation at routine level and to develop from such a study a defined work programme designed to reduce uncertainty.

The government, the regulators, trades unions and the nuclear industry should be informed of such a research programme and asked to support it and to contribute to it as appropriate.

Government should be made aware of CwC UK's interest in this area and CwC UK should seek an official response to this report.

[2] UNSCEAR up to 2000. The authors have not found any subsequent data: http://www.unscear.org/docs/publications/2000/UNSCEAR_2000_Annex-C-CORR.pdf Table 34

3 The evolution of the controversy — a quick start, a slow start, and a forced marriage

As will be related in Section 5, the current theory and practice of radioprotection is based on the discoveries of two separate phenomena — radiation in the form of man-made X-rays in 1895 and radioactivity in the form of a naturally occurring radioactive substance, radium, in 1898.

The physical differences between X-rays and radium are significant; X-rays are penetrating and the source is always outside the body. X-rays can be controlled by shielding materials that absorb the radiation or by turning off the machine. The radiation from radium cannot be turned off. If the radium is outside the body even the dead cells on human skin prevent its alpha rays reaching living tissues but it cannot be controlled at all once it's inside the body, as it was in the 1920s when the women who painted luminous dials ingested it and when radium drinks were sold as health tonics.

Radioprotection as applied to X-rays proceeded rapidly after their discovery. This was because the medical professions drove the development and application of X-rays and they recognised the harmful effects almost as quickly as the benefits. By contrast, the effects of radium took two or three decades to emerge because radium was useful not mainly to doctors but to quacks, entrepreneurs and the military. These factors meant that the principles of protective practice for X-rays were well-established by 1906 (even if it the standards were very lax by modern standards) but it took another 30 years for the hazards of internal radium to be recognised in a completely separate standard. It was admittedly tentative but it was based on research on the physical effects seen in the bones of the dead radium dial painters. The standard was expressed as an upper limit on the amount of radium permitted in a worker's body. The body burden could be calculated from the amount of radon (a decay product of radium) in their breath, as measured by a meter designed for that purpose. On reaching the limit a worker would have to move to a task which did not involve radium.

Despite their essential incompatibility the two paths were made to converge during World War 2. The USA built reactors to enrich uranium for uranium bombs like "Little Boy", which they dropped on Hiroshima, and to change uranium into plutonium for the "Gadget" (the first atomic bomb test) and for "Fat Man" at Nagasaki. The reactors (and the bomb explosions) created other radioactive substances too, so new that there were no data on the damage they might do to the men who were working with them. But nothing could be allowed to slow down the nuclear arms race since Adolf Hitler was known to be developing his own bomb. The good news was that the physicists knew how much radiation energy was given off by any given quantity of any particular one of these man-made substances, so that doses could be conceived in terms analogous to X-ray doses. Better still from the regulatory point of view, all types of exposure — external and internal, natural and novel — could be calculated in apparently scientific units that could be added together as total doses delivered to individual people. The bad news was that this new approach was analogous to a pharmacist opening a Pandora's box of unknown drugs and assuming that the one physical quality he could measure for every substance — "density", for example — was the only thing he needed to know to assess its toxicity and advise on dosage for any cocktail of drugs.

The intervening decades have seen much research and the sacrifice of millions of laboratory animals. There has also been dissent, especially about forms of radioactivity like hot particles that irradiate very small volumes of tissue at high intensity, and about the appearance of elevated disease rates in contaminated locations like Belarus and exposed populations such as the nuclear test veterans. The dissenters have been marginalised and public reassurances have been issued but the doubts remain.

3.1 Windscale and the 'Nuclear Laundry' TV programme

In the early 1980s concern was voiced by people living on the Cumbrian coast about the numbers of people in their community suffering from cancer and, in particular, the number of children suffering from leukaemia. Unofficial investigations showed that, in the small village of Seascale close to the Windscale nuclear plant, childhood leukaemia over a thirty year period had been ten times higher than the national average rate. These concerns became widely publicised on 1st November 1983 when the Yorkshire TV (YTV) documentary 'Windscale – the Nuclear Laundry' was broadcast.[3]

3.2 The Black committee and its successor COMARE

Within weeks of the film's transmission the Thatcher government set up an investigation under Sir Douglas Black which led to the establishment of the advisory Committee on Medical Aspects of Radiation in the Environment (COMARE). Between 1986 and 2016, COMARE produced eight reports on childhood leukaemia and other childhood cancers, examining whether incidence rates could be attributed to releases of radioactivity from fuel reprocessing plant at Sellafield and Dounreay, from nuclear power stations (NPPs), and from the Atomic Weapons Research Establishment and the Royal Ordnance Factory in Berkshire. Epidemiologists and official radiation protection bodies in other countries also investigated. A leukaemia cluster was identified near the French reprocessing plant at Cap de la Hague.[4]

3.3 "Numerous studies" – a meta-analysis

Epidemiologists Baker and Hoel of the University of South Carolina noted in 2007 that in response to the Black committee, "numerous studies" had been conducted in many countries to assess the possible childhood leukaemia risk due to irradiation from nuclear sites. Baker and Hoel reviewed that literature, eventually selecting seventeen studies whose methods and data were sufficiently well-specified to allow them to be compared with each other. This meta-analysis covered 136 nuclear sites in nine countries. The authors report that the majority of studies found elevated rates of childhood leukaemia near the sites, although they were not usually statistically significant. Despite the 'statistically insignificant' nature of the findings, they reported that the excess "cannot be ignored" although they warned that it does not support a hypothesis to explain the elevated rates. An earlier study by Cook-Mozaffari and others did find statistically significant results; they analysed data from England and Wales showing that deaths from leukaemia and other cancers in young people near nuclear facilities were 15% higher than in districts further away.[5]

3.4 Internationally significant implications

According to the LNT risk model, the numbers of leukaemia cases reported by Yorkshire TV in 'Windscale, nuclear laundry', ought not to be observable at the levels of radiation involved, which are close to the levels that people are exposed to from natural background. If it were demonstrated that the reported effects are real and that they are being caused by the radioactivity, the consequent pressure to reduce levels of exposure would be so great that the entire nuclear industry both civil and military would have to be re-tooled at crippling and possibly fatal expense. Government's continued and dogged reluctance to engage in meaningful dialogue around the ionising radiation and health issue can only support the conclusion that a policy of denial and keeping critics at arm's length is preferable to engaging in a process which may prove the critics are correct.

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[3] https://www.youtube.com /watch?v=gidQewCtTqY

[4] Case-control study of leukaemia among young people near La Hague nuclear reprocessing plant: the environmental hypothesis revisited. D. Pobel and J. F. Viel BMJ. 1997 Jan 11; 314(7074): 101–106.

[5] Geographical variation in mortality from leukaemia and other cancers in England and Wales in relation to proximity to nuclear installations, 1969-78 Cook-Mozaffari P, Darby S, Doll R, Forman D, Hermon C, Pike M, Vincent T Br. J. Cancer (1989), 59, 476-485.

4 Resistance to the policy implications arising from the controversy

4.1 Denying significance

Authors of many individual studies that show non-significant leukaemia increases have reported that there was no evidence of an effect.[6] It has been argued [7] that such conclusions are incorrect and that authors "should have reported the observed leukaemia increases but added there was a greater than 5% chance they could have occurred by chance". This principle has recently been supported by a paper endorsed by more than 850 academics which calls for "an end to … the dismissal of possibly crucial effects" through assuming that statistically nonsignificant results are evidence of "no effect" or "no relationship".[8] The authors add "... it is wrong to conclude that two studies are in conflict simply because one had a statistically significant result and the other did not. These errors waste research efforts and misinform policy decisions."

4.2 Elevated leukaemia rates in the absence of nuclear power stations

In addition to the debate over statistical significance of health effects from exposure to ionising radiation some papers argue against any assumption that radiation or releases of radioactivity from nuclear power stations (NPPs) were responsible for causing leukaemia because high rates of the disease were observed in places where there were no NPPs. For example, an editorial by Wakeford in 2014 speculates that, "a generally non-uniform geographical distribution of childhood leukaemia incidence throughout Great Britain suggest[s] that there are important, probably widespread, risk factors that can produce localised aggregations of cases. Perhaps this is the common 'feature' of childhood leukaemia clusters near some nuclear installations?"[9]

4.3 Elevated leukaemia rates before nuclear power stations were built

Wakeford (Fn.9) cites a study [10] of 62 nuclear sites in USA and suggests that elevated leukaemia mortality rates in the 0–9 age group before the NPPs started operating provide evidence that the cause is unrelated to radiation. For the four facilities where incidence data were available, three had higher ratios after start-up, but rates were greater than expected both before and after start-up, and generally remained unchanged. The argument ignores the contribution of pre-existing fallout from atomic weapons tests which will be discussed later in this report.

4.4 Elevated leukaemia rates around potential nuclear power stations

4.4.1 Potential sites in UK

It is frequently said that any causative relationship between leukaemia and cancer and proximity to NPPs is weakened by the observation of high rates in districts which were considered for the construction of NPPs that were never built (so-called "potential" sites). For example, the large study by Cook-Mozaffari et al. mentioned above (Fn.5) showed elevated rates of leukaemia and cancer in districts any part of which lay within 16 km of a nuclear installation. The authors expressed puzzlement since the children living near the

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[6] for example Laurier D, Grosche B, Hall P. Risk of childhood leukaemia in the vicinity of nuclear installations—findings and recent controversies. Acta Oncol. 2002;41(1):14-24. states there was no evidence of leukemia increases near NPPs.

[7] A hypothesis to explain childhood cancers near nuclear power plants Fairlie I, Journal of Environmental Radioactivity 133 (2014) 10 - 17

[8] Amrhein V, Greenland S, McShane B *Retire statistical significance* 21 March 2019 Vol 567 | Nature 305. Supplementary material and list of signatories at https://www.nature.com/magazine-assets/d41586-019-00857-9/data-and-list-of-co-signatories

[9] "Childhood leukaemia and nuclear installations: the long and winding road". R Wakeford. British Journal of Cancer (2014) 111, 1681–1683 https://www.nature.com/articles/bjc2014517

[10] Jablon S., Hrubec Z., Boice J.D. & Stone B.J. (1990) *Cancer in Populations Living Near Nuclear Facilities* Vol. 2. Public Health Service, US Department of Health and Human Services, Bethesda, MD, USA

nuclear installations received too little radiation to explain the disease and they soon returned to their data to conduct a different comparison.[11] They speculated that the areas where nuclear installations were built might have some unknown feature unrelated to radiation or radioactivity that had not been taken into account. They therefore analysed the data for six sites that had been "seriously considered" as locations for nuclear power stations but never used. These so-called "potential sites" were Herbury in Dorset; Luxulyan, Nancekuke and Gwithian in Cornwall; Portskewett near Chepstow in south-east Wales; and Druridge Bay in Northumberland. In addition, the "potential sites" included Heysham in Lancashire and Hartlepool in Cleveland which were established after 1978, the end of the original study period.

Herbury is a small peninsula jutting out into the Fleet lagoon behind Chesil Beach on the south coast of Dorset. It is about 15 km from Winfrith, site of at least eight experimental reactors from 1959 until well after the end of the study period. By design, these studies (Fn.5 &11) deal with nuclear sites in close proximity to each other by excluding districts which overlap. It follows that the wards studied in relation to Herbury would lie mainly in a rural area to the west, while the wards studied in relation to Winfrith would lie to the east and include the conurbations of Poole and Bournemouth. This is a confounding factor since Dr. Alice Stewart had already identified that transmission of infectious diseases in towns masks the onset and diagnosis of leukaemia. A different confounding factor applies to the sites in the west of the country, since the west receives more rainfall, particularly in areas of high ground and it is well known that this creates a differential in the deposition of radioactive fallout from above-ground testing of nuclear weapons and from Chernobyl.[12] Heysham, Portskewett and the three Cornish sites are all in the west. In addition, Heysham is close to the Sellafield-contaminated coast which will be discussed later in this report, while the Portskewett site is close to the River Severn which is contaminated with fallout draining from the Welsh uplands as well as emissions from the other nuclear installations on the English bank, and material from Amersham International and AWE Llanishen in Cardiff which has been discharged further downstream and redistributed by the massive energy of the tides in the Severn Estuary. This leaves only Druridge Bay and Hartlepool on the east coast to provide any credible comparator. It must be borne in mind that ubiquitous weapons test fallout complicates any such considerations, as briefly discussed above.

4.4.2 Potential sites in Germany

A similar debate has been conducted in Germany where in 1995 the German Federal Office for Radiation Protection (Bundesampt für Strahlenschutz -BfS) studied childhood cancer and congenital malformation around NPPs in Bavaria, including potential but unrealised sites.[13] A re-analysis of the data showed that the study reduced risks around operational sites by including very small reactors,[14] and inflated risks around the potential sites by including Rehling, the only one where risk was significantly higher than expected. Rehling is 30km downwind of Gundremmingen, the operational site with the highest risk.[15] Without Rehling, the results were not significant. Interestingly, risks at Rehling and Gundremmingen were almost identical, calling into question the BfS decision to limit its study to disease incidence within 15km of the NPPs. This argument has more recently gained force since the 2008 KiKK

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[11] "Cancer near potential sites of nuclear installations" Cook-Mozaffari P, Darby S, Doll R; in *Childhood Cancer and Nuclear Installations*: eds. Beral V, Roman E, and Bobrow M BMJ 1993 ISBN 0-7279-0815-4

[12] Bentham, G. and Haynes, R, 1995 "Childhood Leukaemia in Great Britain and Fallout from Nuclear Weapons Testing", J. Rad. Prot. 15/1: 37- 43

[13] van Santen F, Irl C, Grosche B, Schoetzau A. Untersuchungen zur Häufigkeit kindlicher bösartiger Neubildungen und angeborener Fehlbildungen in der Umgebung bayerischer kerntechnischer Anlagen. Bericht des Bundesamts für Strahlenschutz vom November 1995.

[14] Cancer rates in children around Bavarian nuclear installations. Dr. Alfred Körblein, 26. June 2003. http://www.alfred-koerblein.de/cancer/downloads/bfs95.pdf

[15] http://www.strahlentelex.de/Stx_08_508_S01-02.pdf

study (discussed below) found a significant result up to 50 km.(Fn.28) The data in another German study[16] which included potential sites do not show that either leukaemia or all malignancies were elevated in the vicinity of the unused sites.[17]

4.5 Selective citation — an example (Dr. Boulton's paper)

The authors of this report were asked to address a paper in which Dr. Frank Boulton reviews a selection of information on ionising radiation and childhood leukaemia.[18] Dr. Boulton is a retired physician who specialised in haematology and haemato-oncology. He was chair of Medact between 2008 and 2012.

The paper is based on literature searches of existing evidence. It states that over 250 references were consulted; half that number are cited. Very few of the studies cited are critical of the prevailing risk model; there are notable omissions.

The paper dismisses any concern that ionising radiation has a causative role in childhood leukaemia in the vicinity of NPPs. The opening section, on "historical aspects" of radiation and leukaemia, refers to the Life Span Study (LSS) as “one of the largest, longest and most thoroughly studied medical cohorts ever" without explaining why it "initially [had] many detractors" or mentioning that it is still subject to criticism. Similarly, it acknowledges that the "Linear No-Threshold" model is not universally accepted but fails to explain why, or why "defining ‘low doses’ is problematical", or why there has "often been more heat than light" over the question of what radiation exposures are "reasonable". The present report provides answers to all these questions; Dr. Boulton's paper does not. It lists a range of studies of nuclear installations and childhood leukaemia. Very few of them suggest that low doses of radiation have anomalously large effects and those that do are dismissed by reference to others which show the opposite. The paper sets out the contradictions but fails to explore the reasons for them.

Two-thirds of the whole paper are occupied by a discussion of how cells may become cancerous through mutation. That section contains many technical terms and concepts which are defined scantily and sometimes not at all. The central thrust appears to be that segments of chromosomal DNA can be translocated; translocations can be caused by IR and, whether caused by IR or not, they are associated with breaks across both strands of DNA, so-called ‘double strand breaks’ (DSBs). Large numbers of DSBs occur naturally. According to Dr. Boulton, they are readily repaired and the repairs are nearly always effective, but misrepaired DSBs can cause cancer.

This is uncontentious and the authors of this report have become familiar with it over many years. The second part of the same section is also technical but is not familiar. It has no apparent relevance to the paper's title and will not be discussed here. It leads up to the suggestion that deficiencies in the immune system of some children, especially those who do not come into contact with infections, might be related to the "characteristic and suggestive peak age of childhood acute lymphoblastic leukaemia presentation". This is followed by a short "cautionary note about the biological effects of ionising radiation" which states, without references, that it has proved difficult to gauge the risk of adult or childhood leukaemias below a radiation dose of about 40 times UK average natural background, and even more difficult to ascertain the risk from actual levels of background.

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[16] Kaletsch, U., Meinert R., Miesner, A., Hoisl, M., Kaatsch, P., Michaelis, J. Epidemiological studies on the incidence of leukemia among children in Germany, Schriftenreihe Reaktorsicherheit und Strahlenschutz, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU-1997-489, GFM Dossenheim 1997

[17] Kaletsch *et al.* 1997 *op. cit*. Appendix II figs. 3.3.27, 3.3.28

[18] "Ionising radiation and childhood leukaemia revisited" Boulton F. Medicine, Conflict and Survival, March 2019. https://doi.org/10.1080/13623699.2019.1571684

Dr. Boulton appears to have overlooked two large case-control studies which show that variations in rates of childhood cancer and leukaemia are clearly associated with varying levels of natural background[19],[20],[21] and confirm the effect published in 1987 by Alice Stewart and George Kneale using data from the case-control Oxford Study of Childhood Cancer (OSCC).[22] Dr. Boulton appears to have changed his position since 2015 when he did cite the Kendall et al. paper.[23] At that time he wrote:

> "Circumstances surrounding residence near a NPP could well encourage some perinatal lymphoblasts to develop genomic instability, disrupting the apoptotic mechanisms and leading to the inappropriate survival of dysfunctional cells, the progeny of which thereby acquire a propensity to develop overt leukaemia. Ionising radiation – internal or external – could well cause an initial somatic mutation leading to perinatal genomic instability, interacting with environmental immune-related mitoses and adding to the risk of ALL(acute lymphoblastic leukaemia) in that population."

His 2019 paper contains nothing on this topic. Instead a very short section relies on an earlier estimate of leukaemia around NPPs[24] and an even earlier report on the theory of radiation risk from a committee drawn from the French Academy of Sciences and National Academy of Medicine.[25] The chair of that committee is a prolific proponent of radiation hormesis — the theory that there is a threshold dose below which radiation confers beneficial effects. The French report consistently argues for hormesis or that there is at least a threshold dose below which no harm is done. Dr. Boulton states:

> "…the French analysis suggests that the radiation risk of leukaemia in children residing near nuclear installations might be even less than that predicted by Linear No Threshold (LNT), strengthening the suggestion that other causes than radiation are needed to explain the observed incidences."

He concludes by proposing that clustering of leukaemia around nuclear installations could arise by chance or as a result of population mixing which he describes as "entirely feasible and well-studied" and that:

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[19] G.M. Kendall, M. P. Little, R. Wakeford, K. J. Bunch, J. C. H. Miles, T. J. Vincent, J. R. Meara, and M. F. G. Murphy. 2013. "A Record-based Case-control Study of Natural Background Radiation and the Incidence of Childhood Leukaemia and Other Cancers in Great Britain during 1980–2006." Leukemia 27 (1): 3–9. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3998763/

[20] Environmental Health Perspectives Background Ionising Radiation and the Risk of Childhood Cancer: A Census-Based Nationwide Cohort Study June 2015 Ben D. Spycher, Judith E. Lupatsch, Marcel Zwahlen, Martin Röösli, Felix Niggli, Michael A. Grotzer, Johannes Rischewski, Matthias Egger, Claudia E. Kuehni, https://ehp.niehs.nih.gov/doi/10.1289/ehp.1408548

[21] See https://www.youtube.com/watch?v=XTijIRsxTSE for a helpful commentary on the significance of the recent case control studies (refs.19,20)

[22] George Kneale and Alice Stewart, Childhood cancers in the U.K. and their relation to background radiation. Radiation and Health 16 203-220.

[23] Frank Boulton (2015) Dangers associated with civil nuclear power programmes: weaponization and nuclear waste, Medicine, Conflict and Survival, 31:2, 100-122, DOI: 10.1080/13623699.2015.1062336

http://dx.doi.org/10.1080/13623699.2015.1062336

[24] Wakeford, R., G. M. Kendall, and M. P. Little. 2009. "The Proportion of Childhood Leukaemia Incidence in Great Britain that May Be Caused by Natural Background Ionising Radiation." Leukemia 23: 770–776. doi:10.1038/leu.2008.342.

[25] Aurengo, A., D. Averbeck, A. Bonnin, B. Le Guen, R. Masse, R. Monier, M. Tubiana, A.-J. Valleron, and F. de Vathaire. 2005. Dose-Effect Relationships and Estimation of the Carcinogenic Effects of Low Doses of Ionising Radiation. Académie des Sciences 2005; Académie Nationale de Médecine. https://pdfs.semanticscholar.org/f8ce/25b6e1167aee90e1b7a5c4567f4793530e3e.pdf

"Childhood ALL constitutes only 0.15% of all new cancers in the UK, so does not impact on the case for or against nuclear activities unless … current radiation risk assessments are seriously wrong – which is highly unlikely."

Against this, the present authors show theoretical and observational reasons to think current risk assessments are in fact seriously wrong for some specific types of exposure associated with routine operation of nuclear power stations.

4.6 Defensiveness and data denial: the 'KiKK' study

The 2008 German study of child cancer, *Kinderkrebs in der Umgebung von Kernkraftwerken (*child cancer in the environs of nuclear power stations) or "KiKK" reignited the public concerns aroused a generation earlier by the YTV film *Windscale the Nuclear Laundry*.

4.6.1 Background to the KiKK study

By 2001 the Bundesampt fur Strahlenschutz had become concerned that the great preponderance of information on leukaemia and radiation comes from "ecological studies" which by definition compare different groups of people for whom no individual data are available. BfS recognised that such studies can produce "enormously erroneous conclusions" and that "Case-control studies, by contrast, can be considerably more reliable, since their analyses are based on individual characteristics of cases of illness and of healthy control persons." The German Commission on Radiological Protection (SSK) reported that, "With such background in mind, the … BfS launched a case-control study … in an effort to obtain more reliable findings with regard to the relationship between children's cancer – especially leukaemias – and the vicinities of nuclear power plants. As part of this effort, a range of groups met in a "round-table" format. As a result of this work, a 12-member body of experts with epidemiological expertise then defined the type of study to be carried out and the pertinent questions to be considered."[26]

4.6.2 Range of experts setting up the KiKK methodology

According to Dr. Sebastian Pflugbeil, President of the German Radiation Protection Society, half of the 12 experts were opposed to nuclear, the other half in favour. Three of them — Dr. Pflugbeil, Dr. Alfred Koerblein and Dr. Hagen Scherb — are overtly critical of the conventional model of radiation risk.[27] In 2001 the expert group started work designing the study, determining that it should investigate whether the risk of contracting cancer by the age of five showed any correlation with the distance between the child's home and a nuclear power plant. The epidemiological research contract went to the University of Mainz in 2003. In 2008 the study was published.[28] It showed that children who lived within 5 km of an NPP had 60% more cancers than the control children and 120% more leukaemia. The roughly doubled leukaemia risk may appear less startling than Windscale's 10-fold excess but it concerned NPPs which are far less polluting than fuel reprocessing installations. It also used a case control method instead of the relatively imprecise but far more commonly used method of comparing rates in areas close to the NPP with more distant areas. Moreover, the effect fell off monotonically out to 50 km, suggesting that it was truly related to the NPPs and not to chance or other factors.

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[26] "Assessment of the Epidemiological Study on Childhood Cancer in the Vicinity of Nuclear Power Plants (KiKK Study) Statement of the Commission on Radiological Protection (Strahlenschutzkommission, SSK)" p.6 http://www.ssk.de/SharedDocs/Beratungsergebnisse_PDF/2008/Kikk_Studie_e.pdf?__blob=publicationFile

[27] http://euradcom.eu/wp-content/uploads/2016/04/declarationredacted.pdf

[28] Spix et al 2008, C., Schmiedel, S., Kaatsch, P., Schulze-Rath, R., Blettner, M., 2008. Case-control study on childhood cancer in the vicinity of nuclear power plants in Germany 1980-2003. Eur. J. Cancer 44, 275-284.

4.6.3 An insider's view of KiKK

In general, official responses to KiKK — notably the SSK assessment (Fn.26) — have not acknowledged that radiation from the power stations could have caused the elevated rates of cancer and leukaemia. Dr. Pflugbeil has recently written:[29]

> "Dear Richard,
>
> I think you know the conflict around the KiKK study. The design was developed by an external expert group – half of them opposed to nuclear, half in favour — under the supervision of two colleagues from the BfS (Federal Office for Radiation Protection). It was a long but fair discussion and most of our crucial points were accepted. After that procedure the study was announced. The cheapest tender was from the Mainz children cancer registry, because that was part of Mainz University and had access to computer expertise and co-workers who would not require payment. But the University had previously published two large studies finding no elevated rates of childhood leukaemia around NPPs. But those studies used a very simple method — a circle without any NPPs compared with a circle that included NPPs.
>
> "We developed a case control study design which was deeper with greater precision. The Mainz team was convinced that they would find the same result as before, in other words there would be no connection between NPPs and children's cancer/leukaemia. But with our prescribed method they found a significant result up to a distance of 50 km between the NPPs and the children's homes. So they had to show that their own earlier results were not reliable. For this reason they ignored the obligation they were under to communicate important information with the controlling expert group which developed the method.
>
> "I was a member of that expert group and was involved in the fight because the study authors published their report before having a final discussion with the expert group and the BfS. In that first publication they minimised the effect as much as possible and concluded that radiation could not, in principle, be the reason for that effect. What a nonsense. We protested. And then the government and the nuclear lobby groups and pro-nuclear authorities – like SSK (Radiation Protection Commission) went into action with conferences and papers to discredit our methods and the results of the KiKK study. They wanted to avoid the only right conclusion, which is that nuclear energy should be abandoned as quickly as possible. This is the context in which the "Assessment" paper of the SSK was written.
>
> "Part of the KiKK project was that in the end colleagues of the expert team would get all the data in order to review the statistical analysis independently as a control of the KiKK study's quality. But the authors of the study have refused to hand over the data either to me or my colleagues or to the BfS.
>
> "Sorry for the long story – but it is nearly impossible to find out the significance of the KiKK-study from the official papers alone."

4.6.4 A European Union response to KiKK

According to a high-level European Union workshop help by MELODI in 2012, [30] KiKK was emulated in several other countries and it was noted that even when the findings were not

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[29] Personal communication 1 May 2019. Reproduced with permission.

[30] The MELODI Association acts at a high level between member nations of EURATOM (one of the founding treaties of the European Union) and members of the European Free Trade Association (EFTA). It exists to coordinate and promote research and "long term competence" on the human health risks associated with low-doses of ionising radiation. It acts at the level of governments in its member nations and at the level of EU institutions, particularly the European Commission. [see Statutes on http://www.melodi-online.eu/]

statistically significant they showed an elevated risk of childhood leukaemia in 0 - 4 year olds living within 5 km of a NPP. The continuous slope to 50 km was not specifically mentioned in the workshop's report;[31] instead it states,

> "The rather consistent pattern of increased leukaemia in this age group needs to be verified, and should not be interpreted as a causal association but may provide clues about a possible link between childhood leukaemia and living near a nuclear power station." The workshop recommended that "Setting up new studies on childhood leukaemia near nuclear installations is not necessary unless they include new features, e.g. a close link to research into the pathogenesis of childhood leukaemia. ..."

It is reasonable to infer that this reluctance to see further studies undertaken is an attempt to deflect attention away from bad news to diminish its potential to damage the prospects of a nuclear renaissance.

4.6.5 Weapons test fallout and childhood leukaemia - the "Nordic" study

The foregoing sections show investigations of the relationship between childhood leukaemia and nuclear installations. Part of the case for denying that radioactivity from the installations caused the increased leukaemia is the claim that weapons tests in the 1950s and '60s caused only a small increase although exposures to internal emitters in the fallout were "larger (generally much larger) than those from nuclear installations", as Professor Wakeford wrote in a 2014 editorial (Fn.9) citing discussions in CERRIE.[32] Professor Wakeford's claim is disputed. The main study considered by CERRIE in connection with weapons fallout and child leukaemia was the "Nordic" study of Darby, Doll and others 1992[33] which examined incidence of leukaemia in the under-5s in Denmark, Sweden, Norway, Iceland and Finland. CERRIE reported that:

> "Although these excess relative risks are statistically significant, the magnitude of the excesses is small. They are compatible with the risks predicted by standard radiation risk models, although they would also be compatible with somewhat larger risks."

Busby had questioned the Darby and Doll study's validity from 1995.[34] The doubts, which he raised again in CERRIE meetings between 2001-'04, turned on the fact that when the weapons tests began, only one country — Denmark — had a cancer registry. The CERRIE majority report states (para.36) that:

> "The Nordic countries have maintained high quality national cancer registries for a period that stretches back to the time of peak atmospheric nuclear weapons testing."

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[31] Laurier D, Grosche B, Auvinen A, Clavel J, Cobaleda C, Dehos A, Hornhardt S, Jacob S, Kaatsch P, Kosti O, Kuehni C, Lightfoot T, Spycher B, Van Nieuwenhuyse A, Wakeford R, Ziegelberger G "Childhood leukaemia risks: from unexplained findings near nuclear installations to recommendations for future research" 18 June 2014. J Radiol Prot. 2014 Sep;34(3):R53-68. https://www.ncbi.nlm.nih.gov/pubmed/24938793

[32] CERRIE: UK Government advisory Committee Examining Radiation Risks of Internal Emitters 2001-2004: https://webarchive.nationalarchives.gov.uk/20140108135440/http://www.cerrie.org/pdfs/cerrie_report_e-book.pdf

[33] Darby SC, Olsen JH, Doll R, Thakrar B, de Nully Brown P, Storm HH et al. (1992) Trends in childhood leukaemia in the Nordic countries in relation to fallout from atmospheric nuclear weapons testing. Br Med J, 304, 1005-9.

[34] Busby, Chris (1995), *Wings of Death: Nuclear Pollution and Human Health,* Aberystwyth: Green Audit ISBN 1-897761-03-1 pp.124-7

While partly true, this is significantly misleading. The Danish registry had been set up in 1943. The other four countries, which had a combined population more than three times greater than Denmark's, didn't set up registries until several years after the tests began and just as the fallout was approaching its peak values, as shown in UN data below.[35]

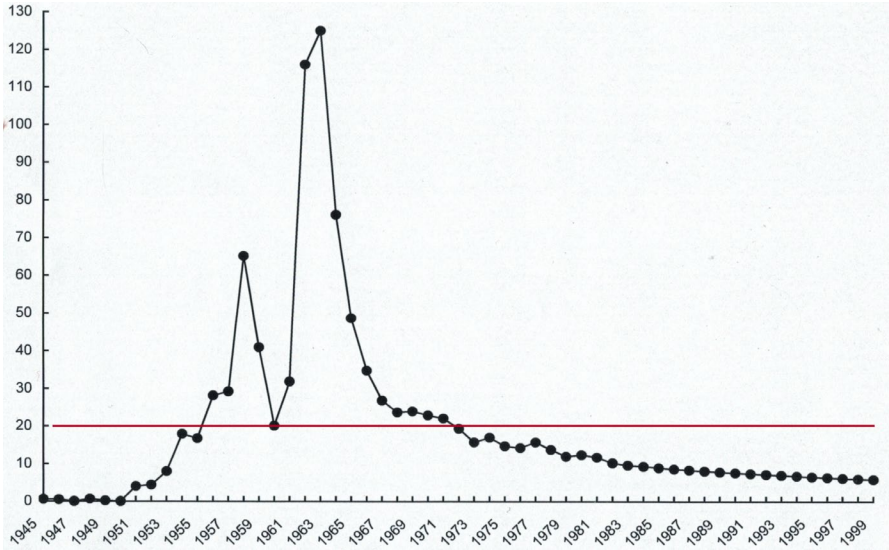

Fig. 1 Average annual effective radiation dose in northern hemisphere from radioactivity in fallout from above-ground weapons tests. Data from UN (35). The vertical axis shows doses in microsieverts. The red line has been added; it represents 20microSv, which is the UK regulatory limit for doses to the public from any single nuclear installation.

.The Nordic study is a hybrid; it splices and merges data-sets that have significant differences. Since Sweden, Norway, Iceland and Finland had no data until 1958 (1961 in the case of the Swedish registry), Darby and Doll could show only the Danish data for the first part of their study. This is represented by the jagged line at the left-hand end of Fig. 2 below. It should be noted that the figure shows two representations of the Danish data for the first part of the study. The annual figures have considerable variation year by year, which is to be expected of a rare disease in a relatively small population (less than 5 million all ages). The line with circles represents the same data but as five-year averages, which is why the line is smoother.

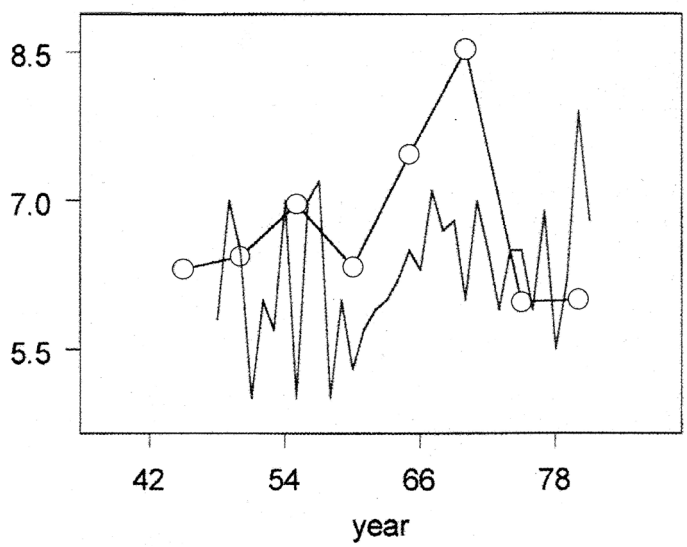

Fig. 2 Rates of childhood leukaemia ages 0-4 in Denmark 1943-77, (line with circles) together with the trend for all five countries given by Darby, Doll et al. 1992. Rates per 100,000. (Source: Fn.41 p.314)

[35] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2000). Sources and Effects of Ionizing Radiation. 2000 Report to the General Assembly, with Scientific Annexes. United Nations, New York.

Once Darby and Doll had spliced in the data for the other four countries, the combined population thereafter was four times that of Denmark alone and for that reason there was less variation, as can be seen in Fig. 2 above. These combined data show a steep and mostly consistent increase that peaks around the maximum fallout doses in the mid-1960s.

Dr. Busby's 1995 book *Wings of Death* (see Fn 35) criticised the Nordic study for inappropriately merging populations which received widely differing fallout doses due to differing levels of rainfall, with different dietary habits and different genetic makeup. Citing BEIR V in 1990[36] Busby refers primarily to " … the wide range of exposure … invalidating comparisons." This is because the time lag between leukaemia expression and dose is known to vary with the dose-level; so Busby wrote (p.125):

> "A low dose has its effect after a longer period of time than a higher dose. … Thus we might expect the range of doses involved in the pooled Nordic sample to smudge out any leukaemia increases …; a simple tell-tale spike … would be unlikely to show up."

The CERRIE minority report noted other studies of weapons test fallout that showed anomalously high rates of leukaemia:-

- a study of child leukaemia in England and Wales [37] stratified by rainfall exposure areas which found a 25% excess in high rainfall areas relative to low rainfall, roughly in agreement with the Danish data and supporting the existence of an error greater than 100-fold;
- a USA study [38] which found an association between child leukaemia in the US and differential exposure to Strontium-90;
- sharp increases in lymphoid leukaemia in children in Denmark over the fallout period; [39]
- the same Danish phenomenon with the suggestion that it had an environmental origin.[40]

The minority report suggested (p.31) a number of mechanisms with potential to explain why leukaemia rates in the collective Nordic countries do not show a consistent relationship with fallout:-

- differences in rainfall causing differences in fallout doses;
- the potential for biphasic dose-responses to reduce leukaemia rates at higher doses; the related phenomenon of in utero deaths at higher doses;
- variation in time-lag at different doses and in populations with different habits and genetic makeup;
- varying levels of competing causes of death in the young;
- different levels of confounding exposures such as chest and obstetric X-rays.

Dr. Busby puts some more detail on these factors in paragraph 6 of Appendix 2 of the present report - the statement from the European Committee on Radiation Risk.

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[36] US National Academy of Sciences committee on Biological Effects of Ionizing Radiation https://www.nap.edu/catalog/1224/health-effects-of-exposure-to-low-levels-of-ionizing-radiation p.261

[37] Bentham G, Haynes R, (1995) 'Childhood Leukaemia in Great Britain and Fallout from Nuclear Weapons Testing', *Journal of Radiological Protection*, 15/1: 37-43.

[38] Archer VE (1987) Association of nuclear fallout with leukemia in the United States. Arch Environ Health, 42, 263-71.

[39] Hakulinen T, Andersen A, Malker B, Pukkala E, Schou G and Tulinius H (1986) Trends in cancer incidence in the Nordic countries. A collaborative study of the five Nordic Cancer Registries. Acta Pathol Microbiol Immunol Scand Suppl, 288, 1-151.

Hansen NE, Karle H and Jensen OM (1983) Trends in the incidence of leukemia in Denmark, 1943-77: an epidemiologic study of 14,000 patients. J Natl Cancer Inst, 71, 697-701.

This account is an outstanding example of the CERRIE majority report's general failure to explain where and why the committee failed to agree, which was a requirement laid on it by Michael Meacher, environment minister in the Blair government, when he set it up in 2001:

> "The committee's review takes account of the views of all parties in the debate on the risks of radiation. It aims to reach consensus where possible. On topics where differences of view remain after its deliberations it will explain the reasons for these and recommend research to try to resolve them. ... CERRIE will produce a report that is agreed by all its members. …"

A detailed account of discussions concerning the Nordic study is provided in Dr. Busby's book *Wolves of Water*[41] and the relevant passage is online.[42] It draws attention to anomalous accounts of the availability of the data, and the discovery that the published volume of Danish Registry data covering a substantial part of the Nordic study period was missing from various libraries. A complete set of the publication was eventually given to Busby by the Registry's founder. The CERRIE majority report states at para. 37:

> "A number of queries were raised by some members concerning the data used in the study. Therefore, experts in Nordic countries were contacted for their views on the quality of the data, and they supported the accuracy of the data used by Darby *et al* (1992)."

The authors of the present report are concerned that the opinion of those experts might have been founded on unreliable information and recommend that consideration be given to a review of the entire issue.

Above all, the CERRIE majority's equivocation about the elevated rate of leukaemia fails to take account of the inevitability of biphasic dose responses which compromise the study of any single endpoint or disease. Professor Wakeford's confidence that the Nordic study means that nuclear industry discharges cannot cause the observed increases in leukaemia rates is misplaced.

5 Perceptions of radiation risk: the historical context

5.1 Early empirical experience: External X rays and swift rational progress

The radiation age began with the discovery of X-rays in 1895 and of radium three years later. X-rays and radium both involved exposing people to ionising radiation which at the time was an unknown phenomenon although life on earth has always been bathed in it. X-rays involved a purely external exposure while radium was principally an internal one. This is an important distinction. The dangers of X-rays were soon recognised and the basic principles of radiation protection for X-rays were described as early as 1906.[43]

It was different with radium. Very early experience showed that when people put vials of radium in their pockets they developed skin lesions but the internal hazards weren't widely recognised for a long time despite some early warnings.[44] It should be noted that radium is an alpha emitter and that the layer of dead cells on human skin is enough to stop alpha rays, so readers may well wonder how glass vials of radium can cause skin lesions — surely they would not be able to pass through the glass. The answer is that it's not the alpha rays that cause the lesions but the beta and gamma rays from the elements (known as "daughters") that radium decays into. Beta and gamma rays are more penetrating and do pass through the glass (and see Fn.48).

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[41] *Wolves of Water:* a study constructed from atomic radiation, morality, epidemiology, science, bias, philosophy and death Busby C. Green Audit 2006. ISBN 1-897761-26-0

[42] *Wolves of Water* pp.305-316http://www.llrc.org/llrc/wings/subtopic/denleuk.pdf

[43] "Early X-ray protection in the United States": Kathren RL *Health Phys.* 8, pp 503-511, 1962

[44] "A note on the action of radium on tissues": Transactions of the Royal Academy of Medicine in Ireland December 1915, 33:347 W. G. Harvey

5.2 Internal contamination: bitter experience and slow progress

In the early part of the 20th century, commercial products and tonic drinks containing radium were thought to be beneficial to health and mine workings rich in radon (a naturally radioactive gas) were used as spas. Industrial applications notoriously included the production of luminous paint. People became far more cautious after the most enthusiastic consumers of the health aids and the women who painted luminous dials for watches, compasses and other instruments began to suffer spontaneous bone fractures, disfigurement and death. This was partly because the dial painters were not trained to avoid ingesting the material and commonly would put their paint brushes between their lips to obtain a good point for the fine detail. Their terrible injuries led to years of empirical scientific inquiry based on examining damage in the victims' body tissues, particularly bone, where radium is deposited.[45] The dial painters' scandal broke in the early 1920s,[46] but it has to be said that the scandal didn't concern the fact of the injuries but rather the employers' resistance to compensating the victims for what was obviously a work-related health problem. This resistance may explain why it wasn't until 1929 that the Advisory Committee on X-Ray and Radium Protection was formed to develop safety standards and why its first report didn't appear until 1934.

5.3 War and political imperatives

In 1941, pressure for increased military production of luminous instruments led to a tentative decision by the Standards Bureau Committee to adopt a limit for radium in a worker's body.[47] It was tentative in the sense that even after some years of research, the committee knew they still didn't have enough information to be confident in their limits.

Nuclear fission of heavy elements had been discovered in 1938. Within a year, Germany was reportedly working on a nuclear bomb and President Roosevelt set up the Manhattan Project to do the same thing. Reactors were built to produce plutonium and the tentative radium exposure limit was extended to cover that, which was rational since both plutonium and radium are alpha-emitting bone seekers. But the reactors inevitably produced other novel radioactive elements in significant quantities and these had different characteristics presenting thousands of workers with unknown health hazards. There was no time to study the effects in post mortem body tissues, as the radium researchers had done. Soon a radical conceptual shift took the learning process in a new direction.

5.4 Closing the black box: imposition of the external paradigm

The change was initiated by Herbert Parker, a British Health Physicist who became head of radiation protection at the Manhattan Project in 1943, just as its first reactor came on stream. His earlier career in British hospitals had made him familiar with X-rays and a kind of cancer therapy that used radium as an external source, confining it in glass tubes and placing them carefully to irradiate tumours.[48] Parker shifted the focus from direct investigation of the internal biological effects of specific substances onto a new idea which could be used to assess the energy received from any source of radiation, internal or external or a mix. To quantify the influence of radiation he used work-related concepts — "force", "movement"

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[45] https://edition.cnn.com/style/article/radium-girls-radioactive-paint/index.html

[46] https://www.npr.org/2014/12/28/373510029/saved-by-a-bad-taste-one-of-the-last-radium-girls-dies-at-107?t=1553167311987

[47] Applying that limit in practice was achieved by a limit on radon in the air inside workplaces, since radon is a decay product of radium, and by measuring radon in a worker's breath — if too much radon was detected they would be moved to other work.

[48] The alpha decays of the radium would not have penetrated the glass so the therapy depended on beta and gamma emissions from radium's decay products (daughters). In marked contrast to the dial painters' problems, this medical application didn't involve radium becoming inextricably mingled with a patient's bones where the alpha decays would have played a large role. The same observation applies to the skin lesions in early radium researchers.

and "acceleration" — which are essentially linear. He called his units "Roentgen equivalent physical" after the discoverer of X-rays, Wilhelm Roentgen. The source of X-rays is always outside the body, reflecting the fact that the risk model was now to be based on average energy delivered externally.

In 1948, the US Atomic Energy Commission pressed the National Committee on Radiation Protection and Measurements (NCRP) to develop safety standards.[49] An especial concern was contamination of body tissue with elements like radium, uranium and plutonium which emit alpha rays. Alphas are intensely damaging to tissue but only within a very short distance. Separate sub-committees were set up — Committee One for external radiation, Committee Two for internal hazards. The external sub-committee completed its work quite quickly but Committee Two was slowed down by the complexities of internal contamination and the lack of information about where radioactive elements were deposited inside the body, how long they stayed there and what biological damage was done. In 1951, impatient with the delays, NCRP's Executive closed down the internal committee and stretched the report of the external committee to cover internal radiation. This was the *forced marriage* of the heading to Part 3 of this report.

Karl Z Morgan, Chair of the discontinued Committee Two, opposed its closure and remained critical of many aspects of radiation protection practice for the rest of his life. After his retirement in 1972 he published a number of papers on internal hazards, including the principle of using correction factors to account for the fact that radioactive elements vary widely in the density of energy they deposit in body tissue and that body organs vary in their sensitivity.[50] The concept of using correction factors is now known as Relative Biological Effectiveness (RBE), which is discussed in 7, *Risk perception discrepancies explained*.

Dr. Morgan was a significant figure within the nuclear industry. His university training was in physics. In 1943, aged 36, he was recruited by the Manhattan Project. The following year, he was appointed Director of the Health Physics Division of the Oak Ridge National Laboratory (the Manhattan Project's plutonium factory). He held the post for 27 years. For 20 years, he was Chair of the internal effects committee of the International Commission on Radiological Protection (ICRP). He was a founder and first president of the (US) National Health Physics Society and the International Radiation Protection Association. He edited Health Physics Journal and co-authored the first textbook on health physics. His book, "The Angry Genie",[51] written when he was 91, lists as "heroes" other insiders who publicly disagreed with the ICRP risk assessments. The heroes include John Gofman, who was the first person to isolate plutonium and who, with RW Stoughton and Glenn Seaborg, created and identified uranium-233; Arthur Tamplin and John Gofman of Lawrence Livermore National Laboratory; Thomas Cochran, a senior scientist in the US nuclear program; Edward Radford, Chair of the NAS committee on the Biological Effects of Ionising Radiation and responsible for its 3rd report; and Professor Alice Stewart.

In 1950, American influence had revived the International X-ray and Radium Protection Committee (IXRPC), which had been dormant during the war.[52] Only two of its members

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[49] NCRP was the successor to the "Advisory Committee on X-Ray and Radium Protection" set up in 1929. Changed name in 1946, reflecting the shift in emphasis. "National *Council* for Radiation Protection" from 1964.

[50] "Cancer and Low Level Ionising Radiation", The Bulletin of Atomic Scientists. Vol 34 September 1978, pp 30-41.

[51] "The Angry Genie: One Man's Walk Through the Nuclear Age": Karl Z. Morgan, with Ken M. Peterson, U of Oklahoma Press 1999 ISBN 978-0-8061-3122-1

[52] This explanation of the International Commission on Radiological Protection's antecedents can be found in various books and on ICRP's website which says: *During World War 2, it was not possible for the committee to meet and it wasn't until the 1950s that another meeting took place*. But it appears that the committee had only ever met once, and that was during a conference of the International Congress of Radiology in 1928. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4756341/

were still alive and one of those was the Chair of the American NCRP. But an international body, rather than a unilateral American one, was needed for reasons of credibility and IXRPC was reborn as the International Commission on Radiological Protection (ICRP). In reality ICRP was just an overseas branch of the NCRP and in 1953 it adopted the NCRP report wholesale.

These events represent the closing of a Black Box, cementing the concept of assessing health effects of both internal and external exposures on the basis of average doses and thereby creating the conditions for the increasingly visceral debate which continues to divide opinion today.

5.5 Reopening the box

Karl Morgan and his heroes criticised the mainstream of radiation protection but they did not openly reject the mainstream concept of dose. It began to be argued that low doses could cause health effects but without any clear and compelling proposal for a causal mechanism. The idea that there is some problem with the dose concept has emerged rather slowly, beginning (as far as the present authors can ascertain) with the observations of R.H. Mole of the Medical Research Council in 1976,[53] which were repeated in the CERRIE majority report (Fn.86) and are now in the scientific literature as a result of Dr. Busby's work. The key reference is *Aspects of DNA damage from internal radionuclides,*[54] which has informed much of this report. An exchange between Dr. Busby and Dr. Jordan in *Genetics*[55] is also relevant, as it has led to the debate between NGOs and the Department for Business, Energy, and Industrial Strategy which will be discussed in 8.2.5.

6 Development of a risk model: the crucial role of the Life Span Study of Hiroshima and Nagasaki survivors in quantifying risks

The controversy over the health impacts of exposure to ionising radiation pivots on perceived shortcomings of the Life Span Study (LSS), an ongoing study of the effects of the two nuclear bombs dropped on Japan in August 1945 — Hiroshima on 6th, Nagasaki on 9th. Within weeks of the bombings the US authorities set up the Atomic Bomb Casualty Commission (ABCC) to gather data on the survivors, known as hibakushas. Under wartime conditions the actual radiation exposures could not be measured but were reconstructed on the hibakushas' memories of where they had been when the bombs detonated and on the basis of later test detonations in the USA. The assessed doses and the hibakushas' health records are the basis of recommendations from the ICRP and hence for official authorisations and dose limits.

6.1 Shortcomings of the LSS

Later sections of this report will consider whether the LSS and the recommendations of the ICRP incorporate all the information necessary for protecting public health in relation to all types of exposure to ionising radiation. The authors of the present report believe that they do not, because uranium and plutonium, which are alpha emitters, must have been large components of the fallout from the bombs and would have been available for inhalation and ingestion. The LSS however have no data on fallout and are therefore silent on their health effects. It is important to understand that the LSS inform only on the effects of external irradiation.

The LSS, moreover, have no unexposed control population. They did originally define a control population of people who had been so far away from the explosions that the gamma

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[53] R.H. Mole, The biological basis of plutonium safety standards, J. Br. Nucl. Energy Soc., 15 (1976) 203-213

[54] Aspects of DNA damage from internal radionuclides: Busby C, in InTech *New Research Directions in DNA Repair* 2013 Chapter 22 https://www.intechopen.com/books/new-research-directions-in-dna-repair/aspects-of-dna-damage-from-internal-radionuclides

[55] http://www.genetics.org/content/203/4/1505 & http://www.genetics.org/content/204/4/1627 and see 8.2.5 of this report

rays and neutrons could not have reached them, but this control was dropped in 1973 when it was determined to be too healthy.[56] Watanabe and others have corrected this flaw by using the population of the entire Hiroshima prefecture and the neighbouring Okayama prefecture as a control.[57] The inhabitants of those areas were so far from the hypocentre that they could not have received any external radiation.

The Watanabe study shows that cancer mortality even in the lowest dose LSS group was three times higher than in the Hiroshima and Okayama prefectures group. This 3-fold difference is far greater than the difference between the LSS groups and suggests strongly that the external radiation was not the important factor; the unknown contribution of internal fallout is far more important. Watanabe and colleagues expressed this as: "the contribution of residual radiation, ignored in LSS, is [...] fairly high".

Sawada has examined reports of hair loss and diarrhoea — typical symptoms of high radiation doses — in people who lived more than 5km from the hypocentre.[58] These people were too far away to have been affected by gamma rays and neutrons but the Uranium-bearing black rain is known to have fallen across wide areas. Professor Sawada concludes: "If internal exposures by radioactive material in the fallout from [the] mushroom cloud cause higher cancer effects than external exposures, then all of the conclusions of the ICRP risk model are false. […] The results show clearly that internal exposures have radiological effects out of all proportion to their doses as calculated by the simple energy per unit mass approach."

6.2 Risk perception and dissent.

6.2.1 X-rays, the pioneering Dr Alice Stewart and the Oxford Survey of Child Cancer

Leaving aside the silence of the LSS in respect of fallout and internal radiation, the external risk model quickly came under attack. In 1955 David Hewitt, a colleague of the epidemiologist Dr. Alice Stewart at Oxford University's Social Medicine Department, published a paper showing that rates of child leukaemia mortality approximately doubled between 1930 and 1953.[59] Stewart was already concerned at the death of her 3-year-old god-daughter from leukaemia. This was the beginning of the Oxford Survey of Child Cancer (OSCC), a long-running case control study of prenatal influences. OSCC was based on interviewing two groups of mothers — those whose children had died of cancer or leukaemia, and a group of control mothers who were carefully matched to the bereaved mothers so that the only difference was whether the child was dead or alive. The interviews collected information on a very wide range of lifestyle factors.

The OSCC showed that if a pregnant woman had an abdominal X-ray the chance that the child would die from cancer or leukaemia by its 15th birthday increased by 40%. This is significant for the topic of this report because it allows direct and straightforward comparison with the LSS because the doses at Hiroshima and Nagasaki were assessed on the basis of instantaneous irradiation by gamma rays and neutrons which, like X-rays, are highly penetrating. The LSS showed leukaemia in 1% of the nuclear bomb survivors who had received the highest doses as they were in Zone A, within 1000 metres of the hypocentres. The 40% increase in the chances of children dying by their 15th birthday identified in the OSCC was apparently caused by doses less than a thousandth of the doses experienced in Zone A.

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[56] pp 6-7, ABCC LSS Report 7, 1973

[57] Hiroshima survivors exposed to very low doses of A-bomb primary radiation showed a high risk for cancers Watanabe T et al. Environ Health Prev Med. 2008 Sep; 13(5): 264–270.

[58] Sawada S., 2007 Cover up of the effects of internal exposure by residual radiation from the atomic bombing of Hiroshima and Nagasaki. Med. Confl. Surviv. 23: 58-74

[59] *Some features of leukaemia mortality* British Journal of Preventive and Social Medicine (1955), 9, 82-88 (Fig 5B)

Moreover, there was not a single case of leukaemia in the Hiroshima and Nagasaki population's *in utero* cohort — those who had been conceived between November 1944 and August 1945. This stark contrast between the LSS and the OSCC results shows that it is false to assume, as the conventional radiation risk model does, that effect is always "linear" or strictly proportional to dose.

6.2.2 Weapons test fallout and perinatal mortality

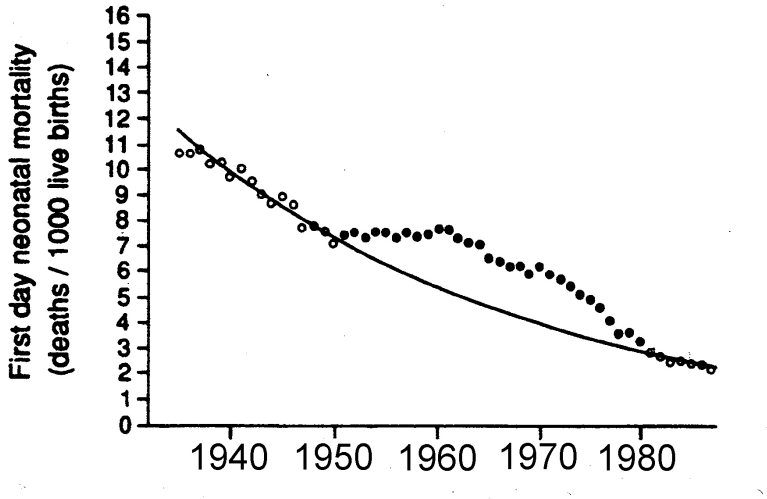

Fig.3: USA rates of deaths in the first day of life (copyright British Medical Journal)

The paper from which the figure above is taken shows six figures for three categories of infant mortality (stillbirth, first day deaths, and 28-days deaths) separately for USA and UK.[60]

The vertical axis above shows numbers of first-day deaths per 1000 live births. The solid curve shows the long-term downward trend of neonatal mortality which has been improving continuously since Victorian times even through two world wars. The circles are annual data. It is clear that the annual data depart from the underlying trend in 1951, the beginning of above-ground nuclear weapons testing, peaking in 1963, the year of the Partial Test Ban Treaty agreement which prohibited test detonations of nuclear weapons except for those conducted underground. The paper suggested that the weapons test fallout was the cause of the deaths and noted that the 1986 Chernobyl accident was followed by a similar increase in early infant mortality. In 1996 the author told Richard Bramhall that he wished he had made this more explicit. He wrote:

> "Professor Ernest Sternglass' original observations on the relationship between geographical rainfall and infant mortality were very fine and exemplary pieces of work, and his treatment by the scientific community was nothing short of appalling.
>
> "… I was extremely tentative about mentioning atmospheric testing in the paper and included it only as a terminating remark, but on looking back I see that Professor Kenneth Cross also mentioned it as an idea in his original paper on the phenomenon in 1973.
>
> "I issued a challenge through my paper in the BMJ in 1992 and at two international paediatric meetings inviting perinatologists to suggest hypotheses alternative to the notion of Strontium fallout as a cause for the disturbances in the falling trend in infant mortality and stillbirth rate. I can now report that no such alternative hypothesis has been advanced. This is weak evidence indeed to

[60] *First day neonatal mortality since 1935: re-examination of the Cross hypothesis.* Whyte R. British Medical Journal 1992 Feb 8;304(6823):343-6.

support the Strontium notion but I can add a little more evidence, as presented a couple of years ago at the European Congress of Perinatology. Where there is adequate data describing first day mortality and stillbirth rate from the 1930s to the present day (and there are very few places which have this information) there is a relationship between the size of the disturbance in mortality data and the expected precipitation of Strontium 90. The countries in the northern hemisphere with twice the fallout over that period experienced twice the attenuation in the fall on mortality rates. There is also no doubt that the phenomenon I described in the BMJ article is visible in all countries for which there is data. "
Dr. Robin Whyte M.B. F.R.C.P, Dept of Paediatrics, Faculty of Medicine, Dalhousie University, Halifax, Nova Scotia.

6.2.3 Nuclear-powered ships and cancer in crews

The 2011 Fukushima accident contaminated the American nuclear-powered ship *Ronald Reagan*, which was nearby at the time. Crew members subsequently suffered high cancer rates which they attributed to the fallout. A court case ensued. In 2014 the US Defense Threat Reduction Agency provided data on the health of the *Ronald Reagan's* crew and a matched control group of over 65,000 who, at the same time, had served on similar US nuclear-powered ships which were not subject to Fukushima fallout. The controls had higher cancer rates than the *Ronald Reagan's* crew and the court case stalled since it appeared that the fallout was not the cause.

In 2020 Busby [61] compared the controls with the relevant age-range of the whole US population in the same period, showing that cancer incidence in the controls was roughly ten times higher. The discrepancy between the controls and the *Ronald Reagan* appears anomalous and may be due to the fact that the *Ronald Reagan's* crew is a relatively small population (<5000) conferring large uncertainties. Alternatively or in addition, data loss due to unexplained factors may conceal health effects. Cancer in the *Ronald Reagan's* crew was nevertheless six times higher than in the relevant sector of the US population.

The paper points out that published doses on external radiation from the reactors in nuclear-powered vessels are similar to doses relating to medical and dental practice, where cancer rates in practitioners are not unexpectedly high. This is in contrast to the unquantified radioactivity emanating from the vessels' reactors. The paper identifies two factors relevant to the role of internal exposures:

- the radioactivity is confined in the same small spaces that the crew also occupy and thus is more likely to become internalised in body tissue than radioactivity dispersed into the environment from nuclear power stations and sources such as outfall pipes, landfill, and incinerators;
- a key difference between crews of nuclear-powered ships and uranium workers. Studies of uranium workers are often cited by people who argue against the suggestion that internal radioactivity has significant effects. However, the uranium studies fail to report wide differences in workers' locations and, hence, exposures. This dilutes the overall effects which are therefore under-reported. Conversely, all members of a ship's crew receive roughly the same internal exposure.

[61] Christopher Busby (2020): High cancer risk in US naval personnel serving in nuclear powered ships, Cancer Investigation, DOI: 10.1080/07357907.2020.1731526

6.2.3.1 A paradigm shift?

The first edition of this report was released in March 2020 soon after *Cancer Investigation* published Busby's paper.(61) In June 2020 *Cancer Investigation* published a letter [i] in which Professor Richard Wakeford, a notable proponent of the ICRP risk model, criticised that paper. Busby has replied. [ii] These two letters move the topic into the sociological and philosophical realm of Scientific Revolutions or Paradigm Shifts, as mentioned in our Introduction. As far as the present authors know, this is the first time the peer reviewed literature has explicitly discussed the idea that a Scientific Revolution in radiation risk modelling might be in progress. The significance of this is that the history of science shows change is driven by individuals. Probably the best known is Galileo. He was not the first to suggest that the earth orbits the sun, and his enduring fame is probably due to his lack of tact, which led to house arrest and a publishing ban because he couldn't be allowed to spread an idea that so threatened biblical and ecclesiastical authority. This reliance on ancient ideas has a modern parallel in the way people who threaten nuclear dogma are dismissed on the totally unscientific grounds that the dogma is supported by a vast majority.

Busby's letter welcomes Wakeford's criticism, pointing out that the adherents of an old model discredit challenges by rejecting the data or its interpretation or by reference to the old model itself. Wakeford does all three, as we outline here.

Addressing the data, Wakeford observes that the 9.2-fold excess of cancers is "dramatically high" and "demands explanation" but at the same time he doubts that it "represents a genuine excess" on the grounds that "such a high rate of cancer in naval personnel would have been readily detected previously." Maybe it had been, but long experience of seeking compensation for radiation injuries in servicemen shows that the authorities don't want such matters discussed. It is most remarkable that the data were published in this instance.

Addressing Busby's interpretation, Wakeford doubts that the ships on which the control group served were in fact nuclear powered because the official navy report doesn't say they were and because Busby "offered no additional evidence" to show they were. This is a criticism of the US report rather than of Busby's paper. Busby's reply is that if the control group did not serve on nuclear ships they are not a valid control group and we would add that an ideal control group is one which is exactly the same as the study group except for the factor (exposure) being investigated. It is rather obvious that if the 65,000 controls were not serving on nuclear powered ships their much higher rate of cancer relative to the same age group of the US population would still demand explanation. And even if the control group were ignored altogether, the crew of USS Ronald Reagan had six times as much cancer as their peers in the US, which also demands explanation. Wakeford has not addressed this.

Wakeford then says it's "pure speculation" that the high number of cases in the controls is due to radiation. He is relying on the old model and ignoring the volume of evidence that challenges it. It ought, instead, to be seen as an instance of "Consistency" - one of the tests that Professor Sir Austin Bradford Hill said should be applied to epidemiology when deciding whether an association of events can be taken to indicate causation; "the lesson here is that broadly the same answer has been reached in quite a wide range of situations and techniques". [iii] The authors of the present report have offered evidence of a range of situations suggesting that, where people inhale, ingest and absorb radioactive particles, disease is far more common than predicted by a model which averages the energy across large volumes of tissue so that those exposures appear to confer low doses.

The two paragraphs above were added after the first edition of this report, so the footnotes are presented here in order to preserve the original footnote numbering.

i) Richard Wakeford (2020) Purportedly high cancer risk among US sailors on nuclear-powered ships, Cancer Investigation, DOI: 10.1080/07357907.2020.1782420

ii) Christopher Busby (2020) Response to Richard Wakeford's letter to the Editor "Purportedly high cancer risk among US sailors on nuclear powered ships.", Cancer Investigation, DOI: 10.1080/07357907.2020.1782569

iii) Bradford Hill "Tests of Causality": Annex 4D p 105: Report of the Committee Examining Radiation Risks of Internal Emitters. www.cerrie.org

6.2.4 Nuclear weapons test atmospheric fallout concentrated near high voltage power lines: the association with increased childhood leukaemia

High voltage power lines cause airborne particles to be concentrated nearby. It has been known for a long time that this is because the electric current causes electrostatic effects.[62]

In 2005 it was discovered that rates of childhood leukaemia were higher in children who lived within 600 metres of power lines.[63] A later analysis including newer data and a longer time period appeared to show that there was no significant effect. That study covered the years, 1962 - 2008, when most of the nuclear weapons test fallout was deposited.[64]Busby has reanalysed the data[65] showing that, since the data were given for five periods within the overall period, each could be examined in the context of variations in the mean annual radiation doses as calculated by the National Radiological Protection Board.

The earliest period — 1962-1969 — began when fallout was at its most intense and the latest ended in 2008. This analysis showed the greatest amounts of fallout were associated with the highest rates of leukaemia, an effect which has diminished as levels of fallout reduced. The effect is not strictly proportional with dose but shows the smallest doses are more dangerous per unit of dose.

This runs counter to the conventional Linear No Threshold expectation that more dose always causes proportionally more effect. A similar inverse trend of risk with falling dose is observable in general studies of leukaemia over the weapons test era and is used falsely to argue that there is no cause for concern about fallout effects.[66],[67]

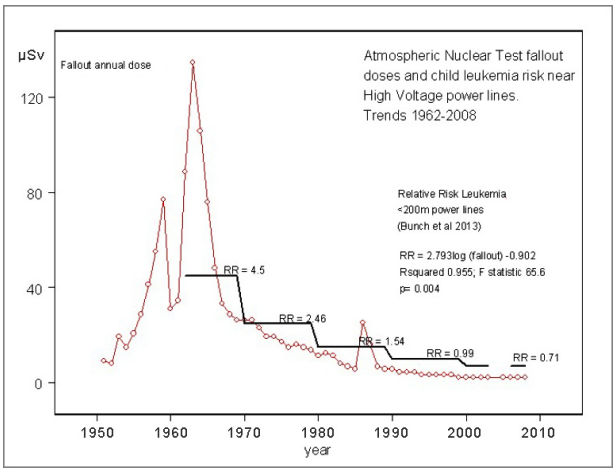

Fig. 4. Trend in annual estimated doses from atmospheric test fallout for England and Wales (red) and Relative Risk of childhood leukaemia within 200m of high voltage power lines in England Wales and Scotland. Year 100 = 2000. Note the spike in doses in 1986, the year of Chernobyl. For discussion, see the paper Fn.65.

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[62] Fews AP, Henshaw D, Wilding RJ, Keitch PA (1999) Corona ions from powerlines and increased exposure to pollutant aerosols. Int J Radiation Biol 75: 1523-1531

[63] Draper G, Vincent T, Kroll ME, Swanson J (2005) Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case control study. *BMJ* 330: 1290.

[64] Bunch KJ, Keegan TJ, Swanson J, Vincent TJ and Murphy MFG (2014) Residential distance at birth from overhead high voltage power lines: childhood cancer in Britain 1962-2008. *Br J Cancer* 110: 1402-1408.

[65] Busby C (2017) Childhood leukemia, atmospheric test fallout and high voltage power distribution lines. *Pediatric Dimensions.* DOI 10.15761/PD.100156. https://www.oatext.com/childhood-leukemia-atmospheric-test-fallout-and-high-voltage-power-distribution-lines.php

[66] Wakeford R, Darby S C and Murphy M F (2010) Temporal trends in childhood leukaemia incidence following exposure to radioactive fallout from atmospheric nuclear weapons testing. *Radiat Environ Biophys* 49: 213–227.

[67] Darby SC, Olsen JH, Doll R, Thakrar B, Brown PD, et al. (1992) Trends in childhood leukaemia in the Nordic countries in relation to fallout from atmospheric nuclear weapons testing. *BMJ* 304: 1005–1009

6.2.5 Increased congenital malformation after Chernobyl

The Chernobyl accident caused an explosion and a fire in the reactor which burned for ten days and dispersed an unreported quantity of Uranium fuel particles.[68] The radioactivity was tracked around the globe. A recent open access review of studies of congenital malformation in Europe and the near East after Chernobyl shows the effects were many times greater than predicted by ICRP risk factors.[69]

The differential is in the order of tens of thousands; for example, one of the studies, recognising that "Evaluation of the effects of radioactive contamination on human populations is important for an understanding of the present and future risk for human health, including the genetic risk", looked at developmental anomalies among human embryos and congenital malformations among newborns in Belarus.[70] It reported, "The data revealed that the incidences of developmental anomalies and congenital malformation from the mostly radionuclide-contaminated rural regions of Belarus reliably exceed the indices in control areas." The dose to individuals in that area was 10 milliSieverts (mSv) so it is relatively straightforward to calculate the discrepancy between the number of abnormalities expected on the basis of the ICRP risk factor for radiation-induced congenital malformations which is based on mice externally irradiated with X-rays, and the number of recorded abnormalities. It is 15,000, which is in the mid-range of the discrepancies reported. This analysis can be contrasted with that of the World Health Organisation's Chernobyl Forum, which is disinclined to challenge orthodox views.[71]

WHO reported (p.86): "There has been a slow but steady increase in congenital malformations recorded in both high and low contamination areas, but the increase does not show a dose-response pattern. […] In fact, there were statistically significantly less congenital abnormalities in the high contamination areas compared with low contamination areas ...". WHO attempted no analysis nor explanation.

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[68] The reactor originally contained around 200 tons of uranium. The authors have not been able to find any reports of the amounts released or remaining.

[69] Schmitz-Feuerhake I, Busby C, Pflugbeil P Genetic Radiation Risks-A Neglected Topic in the Low Dose Debate. Environmental Health and Toxicology 2016. http://dx.doi.org/10.5620/eht.e2016001.

[70] Congenital malformations among newborns and developmental abnormalities among human embryos in Belarus after Chernobyl accident. Feshchenko SP, Schröder HC, Müller WE, Lazjuk G. Cell Mol Biol (Noisy-le-grand). 2002 Jun;48(4):423-6. https://www.ncbi.nlm.nih.gov/pubmed/12064450

[71] WHO Health Effects of the Chernobyl Accident and Special Health Care Programmes: Report of the UN Chernobyl Forum Expert Group "Health": Editors: Burton Bennett, Michael Repacholi, Zhanat Carr. http://www.who.int/ionising_radiation/chernobyl/WHO Report on Chernobyl Health Effects July 06.pdf. The Chernobyl Forum comprises eight United Nations organisations, with representation from the governments of Belarus, Russia and Ukraine.

7 Risk perception discrepancies explained

The dose/risk relationship between the degree of exposure and its expected impact on health has been based on the assumption that the response is linear, as expressed in the Linear No Threshold (LNT) hypothesis which has guided official recommendations and authorisations for exposure levels. Real world evidence undermines the LNT model. This has generated contention which has dominated the debate for decades. The following paragraphs examine some reasons for the discrepancies between some kinds of real-world data and expectation based on ICRP.

7.1 The linear fallacy

The discrepancy can be explained in terms of differences in types of exposure and the limitations of the conventional concept of dose. The passage from the 2006 Chernobyl Forum report quoted in 6.2.4 above reveals that, half a century after the OSCC data suggested that high doses tended to kill the foetus rather than causing an increased leukaemia rate, authorities are still assuming that more dose always causes a greater effect. When the meta-analysis of congenital malformations after Chernobyl (Fn.69) was submitted for review, one of the reviewers asked why the prevalence of malformations generally did not follow a linear model. An explanation was included in the published paper,[72] arguing that radiation exposure of the germ cell or the conceptus or the foetus would cause damage that increased the likelihood of unsurvivable damage and the appearance that birth defects were less prevalent in heavily contaminated regions than in cleaner ones.

7.2 The average dose fallacy

As outlined above in the discussion of Herbert Parker's role, the conventional ICRP concept of dose is conceived as energy averaged over large volumes of tissue. This concept is falsified by the existence of three phenomena that render averaging meaningless for some kinds of internal exposure.

7.2.1 Chemical affinity for DNA

Sr-90 and uranium both have high affinity for DNA on account of their chemical properties. This means that atoms of those elements can become part of the DNA, so that ionisations caused by their decay happen within or very close to the DNA molecule. Chemical affinity is also relevant to the photoelectric effect.

7.2.2 The photoelectric effect or Secondary Photoelectron Effect (SPE)

The 1921 Nobel Prize for physics was awarded to Albert Einstein for his description of the photoelectric effect. This shows that when photon energy from natural background or any radiation source is absorbed by a substance it is re-emitted in the form of extremely short range electrons. Where the incident photon is passing through body tissue, any of the resulting shower of electrons may cause ionisation damage to DNA.

There are two issues that require the SPE to be considered and quantified for radioprotection purposes. One is the possibility that contaminants are present either close to the cell or as part of the cell — uranium, for example, is known to mimic calcium, a critical element in the structure of the DNA molecule, so that substitution of uranium in the place of calcium would increase the absorption of photon energy.[73]

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[72] "How Is It That the ICRP Risk Coefficient Is Wrong?" in 69.

[73] Aspects of DNA Damage from Internal Radionuclides: Christopher Busby 2013 in "New Research Directions in DNA Repair" Ed. Clark Chen, University of California, San Diego, USA
ISBN: 978-953-51-1114-6:DOI: 10.5772/53942
https://www.intechopen.com/books/new-research-directions-in-dna-repair/aspects-of-dna-damage-from-internal-radionuclides

The second issue is to quantify the increase in absorption of photon energy and the potential health impact relative to the radiation risk factors of the ICRP. For this purpose it is necessary to consider that the ability of any element to absorb photon energy is proportional to the 4th or 5th power of the atomic number (Z) of that element.[74] Quantifying the health impact of any high Z element contamination requires comparing it with water, since ICRP ignores the highly differentiated structure of cells and conceives body tissue as having the consistency, density and properties of water.[75]

The value to be attributed to the water molecules derives from the oxygen component rather than the hydrogen, since oxygen has the higher atomic number (Z=8) compared with hydrogen (Z=1). The Z of uranium is 92. The difference between the 4th power of 8 and the 4th power of 92 is 17490, and this is the photon energy absorption enhancement factor conferred by the presence of uranium atoms in any medium or substance, relative to the same number of water molecules in the same medium. Thus the presence of uranium in or close to the cell could be significant in assessing the true health impact of photon energy.

It is instructive to consider the general phenomenon of heavy metal toxicity, since there are other high Z elements besides uranium. Most of them are not radioactive and they have widely differing chemical characteristics but they have toxic and carcinogenic qualities in common for reasons which are not well-known. A 2012 review [76] stated that "Heavy metal-induced toxicity and carcinogenicity involves many mechanistic aspects, some of which are not clearly elucidated or understood." The authors of the present report suggest that the secondary photoelectron effect provides a plausible mechanism to explain heavy metal toxicity and the phenomena outlined in the two paragraphs below.

There are at least two forms of cancer therapy which depend on heavy metals. Cisplatin has been an increasingly common chemotherapeutic treatment for cancer since the 1980s. It is a form of platinum (Z=78) and has been used both with and without artificial irradiation; the addition of artificial radiation has been found to increase the effectiveness with which it kills cancerous cells. It is suggested (ref.75) that Cisplatin functions by fixing the platinum in the DNA molecule where the secondary photoelectrons induced by radiation damage the DNA.

Cisplatin makes the patient feel ill because the platinum is deposited indiscriminately in tissue and in healthy cells as well as cancerous ones. The treatment can kill the cancer cells only because those are replicating more rapidly than the healthy cells and are therefore more susceptible. By contrast, a more discriminating cancer treatment has become available. It uses nanoparticles of gold (Z=79) injected directly into tumours which are then irradiated with X-rays.

This treatment has an advantage over Cisplatin, in that it puts the high Z element directly inside the tumour, not in healthy tissue (and in this connection it should be borne in mind that gold is a known cause of heavy metal toxicity). Moreover, the X-rays are delivered from more than one source focussed onto the tumour from different directions. This gives a high dose to the target cancer but low doses to the healthy tissues that lie between the X-ray source and the tumour.

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[74] The atomic number of an element is the number of protons in the nucleus of every atom of that element. The symbol for atomic number, Z, stands for "Zahl", the German word for number.

[75] Busby Christopher (2019) The Secondary Photoelectron Effect: Gamma Ray Ionisation Enhancement in Tissues from High Atomic Number Elements. In: "Use of Gamma Radiation Techniques in peaceful applications" —Ed. Dr Basim Almayahi. London: IntechOpen. https://www.intechopen.com/online-first/the-secondary-photoelectron-effect-gamma-ray-ionisation-enhancement-in-tissues-from-high-atomic-numb July 23rd 2019 DOI: 10.5772/intechopen.86779

[76] Molecular, Clinical and Environmental Toxicology 24 April 2012 pp 133-164 Heavy Metal Toxicity and the Environment Paul B. Tchounwou, Clement G. Yedjou, Anita K. Patloll, Dwayne J. Sutton https://link.springer.com/chapter/10.1007%2F978-3-7643-8340-4_6

The uncorrected text is accessible at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4144270/

It is suggested (ref.75) that burns and necrosis around wires inserted in patients' jaws during reconstructive surgery for mandibular cancer are evidence of damage caused by the SPE. Measurements of radiation dose and biological effect within 10 microns of gold foil implanted in tissue have been made, showing a 100-fold enhancement of dose and a 50-fold enhancement of biological damage.[77] The genotoxic effects of uranium exposure are now well established both in human populations and in *in vitro* studies [refs. 12–20 in Fn. 75].

These effects cannot be explained by uranium's intrinsic alpha activity, and indeed one of the experiments cited in 75 revealed genetic effects in the absence of alpha decays. Uranium is known to bind strongly to DNA *in vitro*, and since the 1960s has been used (in the form of the uranyl ion) to stain chromosomes so that they can be seen under electron microscopes. Assuming that uranium has the same propensity to bind to DNA in living cells (which, as far as the present authors know, has yet to be established) it represents a focus for absorbing photon radiation and emitting it as extremely localised electron showers on or close to the DNA molecule.

The UK Health Protection Agency acknowledged the SPE so far as it applies to uranium particles but attributed very small risk enhancements to this mechanism[78],[79]. Their reasoning has been rebutted.[80] Similarly, HPA acknowledged the reality of the SPE as it applies to soluble uranium bound to DNA [81] but used false reasoning to minimise its significance.

The present authors have presented the UK Department for Business, Energy and Industrial Strategy (BEIS) with a rebuttal of HPA's argument (in Fn.81), showing that they are confused about the basic physics of the photoelectric effect. A little more detail is given at footnote [82] but the matter is too complex for this report. No reply has been received and the topic is included in the proposed agenda for Joint Fact Finding (JFF) with BEIS. Discussions about JFF are ongoing (see 8.2.7 below).

Taking the SPE fully into account would have significant implications for regulating uranium from using and testing weapons including depleted uranium, routine discharges from nuclear power stations, and from fuel manufacture and reprocessing. Advice on reactor accidents would need to be revised. Other issues such as fracking would be affected.

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[77] Regulla DF, Hieber LB, Seidenbusch M. Physical and biological interface dose effects in tissue due to X-ray induced release of secondary radiation from metallic gold surfaces. Radiation Research. 1998;150:92-100

[78] Pattison JE, Hugtenburg RP, Green S. Enhancement of natural background gamma-radiation dose around uranium micro-particles in the human body. Journal of the Royal Society Interface. 2010;**7**(45):603-611. DOI: 10.1098/rsif.2009.0300

[79] Eakins JS, Jansen JTM, Tanner RJ.A Monte Carlo analysis of possible cell dose enhancements effects by Uranium microparticles in photon fields. Radiation Protection Dosimetry. 2011;143(2-4):177-180. DOI: 10.1093/rpd/ncq398

[80] Reference as Fn.75 section 10

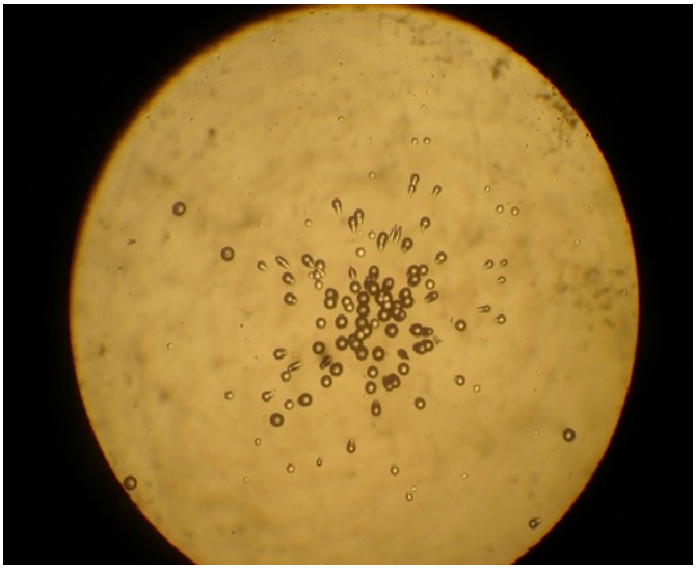
[81] Risks from ionising radiation: S F Mobbs, C R Muirhead, J D Harrison HPA-RPD-066 Para.5.7 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/337141/HPA-RPD-066_for_website2.pdf Section 5.7.

[82] HPA's argument is confused, first in comparing Auger electrons with photoelectrons emitted from Uranium, which is invalid, and then in claiming that the atomic number Z of an element determines the range of the secondary photoelectrons, which is untrue.

7.3 Alpha-emitting particles

Nuclear weapons, reactor disasters and the routine operation of nuclear installations release nano-particles of plutonium and uranium to the environment. The United Nations has published data quantifying releases to the air from NPPs.[83] Such particles are also present in aqueous discharges. Particles up to 29 microns are inhalable and are re-suspended in air at low wind speeds. Wave action re-suspends particles close to coasts. Scavenging vehicles on beaches use Groundhog detectors which are incapable of detecting alpha and beta emitting particles and can only detect particles of the gamma emitter Americium down to a limit of 200 microns.

The official view of the smaller particles is that the doses incurred from inhaling them are too small to cause detectable health effects, and none of the four environment agencies in the UK collects data on such particles in marine sediments or beaches.[84] Such particles can be detected using relatively cheap techniques. The image below was found by Chris Busby in 2018 in dust shaken from the engine air filter obtained by the Stop Hinkley group from a vehicle driven exclusively within 5 km of Hinkley Point power station.



This image shows radiation damage from the alpha decays of a particle a few microns across. The technique employs flat sheets of CR39 plastic and is conventionally used for detecting radon gas in buildings. Each of the circular marks shows the impact of a single alpha ray striking the CR39 more or less at right angles. The elongated marks show the effect of an oblique impact. Alpha tracks that do not travel towards the plastic are not detected. The particle that is the radiation source is probably Uranium-238, though it could be an alloy of uranium, americium and plutonium. This particle was in a small randomly selected portion of the engine air filter from a vehicle that had been used exclusively in the vicinity of Hinkley Point nuclear power station. The filter dust contained many further particles. Methods such as the “groundhog” systems used by the environment agencies for detecting hot particles on beaches near Sellafield and Dounreay are incapable of detecting these respirable particles.

Hot particles became of interest after the Yorkshire TV programme *Windscale the Nuclear Laundry*. David Crouch at the Science Policy Research Unit, Sussex University, reviewed the Black Report from a sociological standpoint, highlighting the uncertainties and knowledge gaps, especially those which concerned alpha-emitting isotopes; "uncertainties in the

[83] SOURCES AND EFFECTS OF IONISING RADIATION: United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes UNITED NATIONS New York, 2000. VOLUME I: SOURCES http://www.unscear.org/docs/publications/2000/UNSCEAR_2000_Annex-C-CORR.pdf Table 34

[84] Replies from Environment Agency, Scottish Environment Agency, Natural Resources Wales, and Northern Ireland Environment Agency to LLRC enquiries in 2018.

dosimetry of alpha-emitters in children and the foetus are acute".[85] Among many references, he cited R. H. Mole of the Medical Research Council Radiobiology Unit whose opinion was that, "predicting the effect of ionising radiation on children is *a biological minefield* " and that "at the cellular level, alpha-particle dose averaged throughout the tissue may be considered biologically almost meaningless", which was restated by the Committee Examining Radiation Risks of Internal Emitters in 2004.[86]

Crouch's references might have gone further back in time if he had been aware of the hot particle controversy in the USA but Karl Morgan's book (51) was not published until 1999. Morgan writes that "the Hot Particle Problem (HPP)" arose during the first five years of plutonium production at Hanford. Herbert Parker wrote reports on "this serious problem" in 1945 and 1946. According to Morgan, "for several years the HPP dominated discussions" but ceased to be dominant after the Atomic Energy Commission rigged the appointments to its Advisory Committee of Competent Authority. For Morgan this was "an early example of [his] profession's prostitution". Similarly the caveat in ICRP's Draft *2005 Recommendations'* that, "The absorbed dose distribution for radionuclides emitting alpha particles, soft beta particles, low-energy photons, and Auger electrons may be highly heterogeneous" is not carried into the actual practice of radioprotection.

7.4 European Committee on Radiation Risk (ECRR): the Committee's role in addressing the shortcomings of ICRP

The ECRR was formed in 1997 to provide an alternative body of scientific advice to redress the shortcomings of the ICRP's approach. Recommendations on that topic were published in 2003 and 2010. A thorough review of the ECRR's work is far beyond the scope of this report. A technical overview by the Scientific Secretary Chris Busby is Appendix 2. It acknowledges that even that account is incomplete. The 2010 Recommendations are however still in print [87] and a new edition is to be published in 2019.

The ECRR Recommendations identify ICRP's failure to address the problematic nature of its macroscopic quantities, even though ICRP acknowledged the difficulty in 1990. To redress this failure the ECRR has revived the ICRP's long-abandoned idea of applying weighting factors in considering the risks of internal insoluble particulates. ECRR notes that this is in line with weighting factors that ICRP does use for differences in the biological effectiveness of various radiation types and the fact that some body organs are more radiosensitive than others.

This approach has the great advantage that, although the true risks of doses from internal exposures may be higher than presently supposed by ICRP, there is no need to alter the present legal standards for maximum permissible doses because the ECRR uses a more accurate method to recalculate the doses themselves. Regulation can therefore continue seamlessly. To this end, ECRR has revived the hazard enhancement weighting factor "N" of the original ICRP model. "N" has two components "termed biophysical hazard factors", W_J, and "isotope biochemical factors" W_K. The example of interest in respect of hot particles is "Internal insoluble particulate" with a W_J factor of between 20 and 1000 depending on the particle size and the dose, which can be calculated from the half-lives of the relevant

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[85] Science and trans-science in radiation risk assessment: child cancer around the nuclear fuel reprocessing plant at Sellafield, U.K. Crouch, D. *The Science of the Total Environment,* 53 (1986) 201--216

[86] CERRIE Majority Report https://webarchive.nationalarchives.gov.uk/20140108135440/http://www.cerrie.org/pdfs/cerrie_report_e-book.pdf Chapter 2.1 paragraph 11.

[87] 2010 Recommendations of the European Committee on Radiation Risk: "The Health Effects of Exposure to Low Doses of Ionizing Radiation" Regulators' Edition: Brussels 2010 ISBN 978-1-897761-16-8

elements and isotopes in the particle. ECRR notes that in 1974 the enhancement of dose for hot particles of plutonium oxide was calculated at 115,000-fold.[88]

7.5 Sea to land transfer as a mechanism leading to hot particle exposure

Early COMARE reports reveal concern about the potential for radioactive particles discharged to the sea to return to the land. COMARE's second report in 1988 [89] on the leukaemia cluster near Dounreay expressed unease about "possible inhomogeneities in dose distribution, uncertainties about relevant target tissues and uncertainties about the chemical and physical characteristics of the nuclides involved which might lead to general values not being applicable for some specific situations." It reported that:

"As at Sellafield, a proportion of the population exposure at Dounreay comes from the discharge of actinides such as plutonium and americium which emit alpha particles which have a high LET. High LET radiation causes more biological damage than low LET radiation for the same absorbed dose."

The same report speculated that biological effects of particular types of radioactive materials may be much greater than has been supposed. Noting that contamination of houses had been discovered, it recommended monitoring. The third report, on childhood cancer in Berkshire, recommended similar monitoring around the Atomic Weapons Research Establishment and the Royal Ordnance Factory.[90] Several studies of radioactivity in household dust (especially plutonium and americium) were undertaken[91],[92],[93] on the basis of which COMARE concluded that "results imply doses which are extremely small."[94]

Earlier sections of the present report reveal the limitations of assessing the health effects of internalised alpha emitters on the simplistic absorbed dose model yet COMARE has not revisited the household dust topic since 1996 except to reiterate the same point about "extremely small doses". A further report has, however, come to light. Dated 1994, it includes a foreword added in 2000 by the Scottish Environment Protection Agency (SEPA) which identifies it as a second draft, never finalised, of an investigation of plutonium in household dust in Thurso, nine miles along the coast from the Dounreay nuclear facility.[95] It was triggered by earlier findings that Dounreay workers' houses had higher plutonium levels than other houses.

The draft confirms that the differential was real with the clear inference that the plutonium was being imported on contaminated clothing and SEPA's foreword ends with an assurance that the site operators were improving hygiene. In the draft report, however, the data were

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[88] Tamplin A.R and Cochran T.B., (1974) Radiation standards for hot particles. A report on the inadequacy of existing radiation protection standards related to internal exposure of man to insoluble particles of plutonium and other alpha emitting hot particles. (Washington DC: National Resources Defense Council).

[89] COMARE Second Report 1988. Investigation of the possible increased incidence of childhood cancer in young people near the Dounreay Nuclear Establishment, Caithness, Scotland.

[90] COMARE Third report 1989. Report on the Incidence of Childhood Cancer in the West Berkshire and North Hampshire area in which are situated the Atomic Weapons Research Establishment, Aldermaston and Royal Ordnance Factory, Burghfield.

[91] Goddard AHJ et al (1986) Household particulate survey (Radioactivity in house dust in West Cumbria and its significance). Report DOE/RW/87033, HMSO London

[92] Heslop JA Reed G (1994) Household particulate survey (Radioactivity in household dust in Seascale and Thurso and its significance). DOE/HMIP/RR94/015

[93] Fry F Green N Dodd NJ Hammond DJ (1985) Radionuclides in house dust NRPB-R181

[94] COMARE Fourth report. The Incidence of cancer and leukemia in young people in the vicinity of the Sellafield site, West Cumbria: Further studies and an update of the situation since the publication of the report of the Black Advisory Group in 1984. Para. 3.84.

[95] Follow-up studies on radioactivity in household dust in Thurso, ICI Chemicals & Polymers Ltd Tracerco June 1994 Reference : AH1943

stratified to distinguish three classes of house: those inhabited by people who worked on potentially contaminated parts of the Dounreay site; those who worked on clean parts of Dounreay; and those who had nothing to do with Dounreay. There was no difference between the clean workers' houses and the non-Dounreay houses. A control study in Banff, 100 sea miles away from Dounreay, showed only natural radioactivity and fallout from atomic weapons tests and Chernobyl.

Plutonium levels found in the Thurso houses were statistically significantly higher than in Banff. The draft report acknowledges that marine spray is a possible mechanism for transferring plutonium and americium onto the land. This mechanism had been discussed in the 2nd and 3rd COMARE reports and previously had been demonstrated in Cumbria in 1984 showing that the effect observable in the data declined with distance from the sea up to 9 km inland with no suggestion that the downward trend was not continuing beyond 9 km.[96] The houses in Thurso did not show a decreasing trend with increasing distance from the sea but they were all within 1.6 km of the sea and the draft report acknowledges that the local topography was complex. It therefore appears that a study of only 34 houses, close to the sea, and potentially affected by unknown lifestyle factors cannot allow reliable conclusions to be drawn about any trend with distance.

The potential for the findings to embarrass the nuclear industry so soon after the discovery of a leukaemia cluster centred on Thurso may explain the author's reluctance to complete the study and SEPA's silence on sea-to-land transfer.

COMARE's fourth report summarised the investigations of house dust but concluded that the doses from inhalation or ingestion of radioactivity in the dust could not have been large enough to have any discernible impact on rates of disease. COMARE's subsequent work has not revisited the topic.

8 Paradigm collapse; Reluctance to engage in meaningful dialogue

During more than 25 years' experience of presenting the arguments outlined in this report the authors have seen government officials, industry representatives and advisers persist in the claim that there is no evidence to challenge LNT and that a scientific "consensus" supports that model. If pressed on the scientific detail, they refer to people who advocate that small doses of radiation are beneficial and suggest that LNT represents the sensible middle ground between irrational extremes. In response, the authors have advocated that it is unscientific to believe any particular view is trustworthy merely because it is well supported by opinion, and that scientific method holds that a single reliable result that falsifies a consensus is enough to require a review.

We have observed four tendencies:

1. official radiation risk agencies have become increasingly remote, anonymous and unapproachable;
2. other agencies are increasingly unwilling to discuss the science of radiation risk;
3. access to data on human health has become increasingly restricted, especially for small geographical areas.

There are no resources for expanding on these here.

4. The fourth tendency is that investigations are likely to occur only where the issues have received enough public exposure to engage the interest of politicians; this is briefly addressed in the following account of dialogues and investigations since 1998. It is limited to events and processes in which the authors of this report have been directly involved but we are not unique, as shown by the "insider's view of KiKK" (4.6.3) and the experience of Independent WHO (8.2 below), for just two examples

[96] The transfer to land of actinide-bearing sediments from the Irish Sea by spray. Eakins J D, Lally A E, Environmental and Medical Sciences Division, Atomic Energy Research Establishment, Harwell, Oxfordshire (United Kingdom) The Science of the Total Environment, 35 (1984) 23-32

8.1 **Dialogues** in which the authors of this report have been involved

8.1.1 STOA: European Parliament "Scientific and Technical Options Analysis" 1998

This process was initiated by Members of the European Parliament Paul Lannoye and Nuala Aherne following widespread public concern about certain provisions of the 1996 Basic Safety Standards Directive which set limits on the concentrations and gross quantities of radioactivity in materials that could be deregulated and sold for recycling or reuse — so-called "free release" materials.

Entitled *'Survey and valuation of criticism of basic safety standards for the protection of workers and the public against ionising radiation",* a workshop was convened in Brussels, February 5th 1998. Alice Stewart, Rosalie Bertell, Carmel Mothersill, Colin Seymour, Chris Busby, Jean-Francois Viel, Heiko Ziggel, David Sumner and others gave presentations. A large proportion of the information was critical of the ICRP risk model. The Secretary of the ICRP replied that the ICRP's recommendations have no statutory force and that people are free to follow other advice.

The form and purpose of STOA workshops was laid out in a preparatory "Workshop Paper":

> "STOA ... carries out projects which have been proposed by Committees of the European Parliament. ... The primary purpose of a STOA study, as the one expected to arise from the Workshop under consideration, is to present the most significant alternative policy options in a given policy domain. It is a highly targeted critical assessment, useful to parliamentarians whose task is to scrutinise and where appropriate amend legislative proposals submitted for their consideration. The study must be carried out with such accuracy and focus that the option can be summarised in an options brief of no more than 2 pages which is published separately from the main study for the rapid and effective information of Members of the European Parliament. The study itself presents the data and arguments that support the policy options that have been identified in the Options Brief".

A draft Final study by the late Professor P.A. Assimakopoulos was produced.[97] It was extensively criticised by the MEPs who originally proposed the Workshop. They pointed out that the Workshop had been designed to elucidate and evaluate the main criticisms of standards based on ICRP. They complained that Professor Assimakopoulos' draft contained "extensive and sometimes misleading advocacy of the existing standards and repeatedly made the false assertion that a linear dose-response relationship is the most conservative" (precautionary).

No final report is known. A request to the library of the European Parliament in 2009 returned only a list of STOA publications for the relevant period. It includes the title of the Assimakopoulos draft report but describes it as a "background paper" written in preparation of the workshop. The list states that the workshop would result in a study to be published "in due course". Nothing more is known to the present authors, one of whom attended the workshop.

8.1.2 SAFEGROUNDS

SAFEGROUNDS was a high level stakeholder engagement process dedicated to developing good practice guidance for managing and remediating contaminated land on nuclear industry and defence sites. It ran continuously from 1999 to 2012 with a broad range of participants.[98] A consistent concern was that the guidance should be accessible to people

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[97] 'Survey and valuation of criticism of basic safety standards for the protection of workers and the public against ionising radiation. - Final study PE 167.161 EN - ' by P.A. Assimakopoulos, K.G. Ioannides and A M.P. Assimakopoulos, Ioannina, February 1998.

[98] **SAFEGROUNDS** is an acronym: **SAF**ety and **E**nvironmental **G**uidance for the **R**emediation of contaminated land **o**n **U**K **N**uclear and **D**efence **S**ites.

who lived near the sites (so-called "over the fence stakeholders") who were likely to be concerned about potential contamination and to consult NGOs.

The Low Level Radiation Campaign's (LLRC) representative urged that guidance documents should inform all stakeholders about the scope and nature of the radiological issues likely to arise. Consequently a 2005 document on risk assessment included an Appendix.[99] It outlined three opinions on radiation risk: that of ICRP; that of the European Committee on Radiation Risk (ECRR) which, based on scientific considerations similar to those outlined in the present report, advises more precautionary risk factors; and that of the US Health Physics Society which advocates hormesis. It gave a competent but brief summary of the differences between the three positions but left the underlying scientific evidence almost entirely unexplored.

Safegrounds was discontinued in 2012, allegedly for lack of money. Document W15 was subsequently deleted from the Safegrounds website although documents that cite it remain.[100] A director of CIRIA, which provided the Safegrounds secretariat, has recently told LLRC that there is no record of who made the decision to delete Guidance document W15.

The last act of Safegrounds was to finalise an exposition of the science behind the ICRP and ECRR approaches to quantifying radiation risk. The NGOs had wanted a dialogue about the reasons for the differing views, but this was resisted by the Health Protection Agency (HPA) which was willing only to provide a statement of its position with no discussion nor negotiation. LLRC was left with no option but to outline the evidence that leads the campaign to believe that ECRR's advice is based more soundly in scientific principles than ICRP's and to describe some of the unresolved discussions.[101] The Nuclear Consultation Group provided a separate overview of the *significant lack of consensus on the definition of LLR risk, and hence current LLR risk policy.*[102] A contractor summarised some of the issues.[103] In a preface to the contractor's report, HPA wrote*;*

> "HPA is unable to endorse this summary document primarily because it unavoidably gives a misleading view, leaving the uninformed reader to question the strength of epidemiological and experimental data providing the scientific

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Chaired by the late Andy Thomas of the nuclear industry's Safety Directors' Forum. **Secretariat** by CIRIA (ciria.org).

Regular participants (* indicates the four participants who acted as the steering group):
Atomic Weapons Establishment; British Energy; British Nuclear Group; Defence Estates; Environment Agency; Future Solutions; Gloucester City Council; Health and Safety Executive; Low Level Radiation Campaign (**Richard Bramhall*); Magnox Electric North; Magnox Electric South; Ministry of Defence; National Nuclear Laboratory; National Radiological Protection Board (to 2005; = Health Protection Agency (HPA) from 2005 [HPA=Public Health England from 2013]); Nexia Solutions (**Peter Booth*); North Highland College; Nuclear Consultation Group; Nuclear Decommissioning Authority; Nuclear Installations Inspectorate; Oxfordshire County Council; Parents Concerned About Hinkley; Scottish Environment Protection Agency; Scottish Executive; Sellafield Ltd; Stop Hinkley; Nuclear Free Local Authorities; UKAEA (**Mike Pearl*); University of Highlands & Islands; University of the West of England/U of Warwick (**Paul Dorfman*); Welsh Anti-Nuclear Alliance.

[99] SMITH, G (2005) *Assessments of health and environmental risks of management options for contaminated land*, W15 CIRIA, London.

[100] SAFEGROUNDS Good Practice Guidance for site characterisation Version 2 Towler P et al CIRIA W30 2009 http://www.safegrounds.com/pdfs/w30_safegrounds_site_characterisation.pdf (p.21) (accessed 8th June 2019); and SAFEGROUNDS Guide to the comparison of contaminated land options; Penfold J CIRIA W28 2009 (Section 1.4.3 and footnote 3 of that document) which cites a slightly amended version of W15 republished with the same title in 2007. http://www.safegrounds.com/pdfs/w28_safegrounds_options_comparison.pdf (accessed 20th May 2019).

[101] http://www.safegrounds.com/pdfs/debate_papers/LLRC_RB.pdf

[102] http://www.safegrounds.com/pdfs/debate_papers/WARWICK_PD.pdf

[103] http://www.safegrounds.com/pdfs/W39_safegrounds_Debate_paper_Final_(hi).pdf

basis for the ICRP protection system. The ICRP protection system is accepted by the majority of scientists working in this area and is implemented in regulatory systems worldwide. In attempting to provide a balanced account of the views submitted by the three members of the SAFEGROUNDS Steering Group, the summary document does not do justice to the substantial body of evidence on radiation risks, accrued over many decades, providing an international scientific consensus. The report does not present a detailed scientific review of the data and so it cannot be used to resolve the debate or provide recommendations."

LLRC's parallel preface said that HPA's position was unscientific because the weight of opinion is irrelevant; NCG wrote that the "institutional definition" of low level radiation risk remains highly controversial and open to critical analysis (ref.103 p.6)

The HPA position paper addressed only one of the scientific issues discussed in the LLRC paper. This concerned the Secondary Photoelectron Effect (SPE). As outlined elsewhere in this report, HPA's discussion of the phenomenon makes an error that suggests a failure to understand its scientific basis and that consequently HPA's dismissal of its significance for radiation protection is unreliable. After nearly a decade this remains unresolved.

CIRIA published two of the three position papers (101,102) and Collier's summary (103). HPA's paper remained under HPA control and CIRIA merely provided a link to it. Purged of any reference to its origin in SAFEGROUNDS, it was published in the Journal of Radiation Protection and was self-published in 2010 by HPA. [104] It was included in the Westminster government's 2010 Justification of Hinkley Point C power station. The error relating to the SPE is common to all versions.

8.1.3 Environment Agency

In the early 2000s, LLRC was corresponding with the Environment Agency, resisting Agency authorisations which British Nuclear Fuels Ltd was seeking for disposal of radioactive waste from Magnox power station sites. Two senior Agency staff,[105] reporting to the Chief Executive and the Chair of the Board, met LLRC in January 2002 and attempted to dispose of some of the epidemiological evidence relating to Chernobyl. An Environment Agency observer was present at every meeting of CERRIE 2001 - 2004 (see 8.2.4).

LLRC holds a substantial archive of internal Environment Agency and Scottish Environmental Protection Agency correspondence, mostly obtained through a Freedom of Information request in 2007. Much of it concerns the uncertainties in ICRP risk factors, ICRP's lack of urgency in considering review of the risk factors, and the consequent suggestion that the Agency ought to conduct its own research.

The correspondence reveals that staff who were representing the Agency in Nuclear Decommissioning Authority stakeholder dialogues were uneasy about encountering LLRC's views there and that they were seeking advice on how to deal with them. One of the responses said that LLRC "had a point". The current situation is that the Agency's representatives in the BEIS Nuclear NGO Forum implicitly endorse ICRP's risk factors and have written that, while they are willing to attend meetings to explain their approach to regulation, they will not discuss radiation risk.[106]

8.1.4 Committee Examining Radiation Risks of Internal Emitters (CERRIE)

By 2000 public pressure had persuaded Environment Minister Michael Meacher not to implement the EU "free release" proposals referred to above. In 2001 Michael Meacher and Yvette Cooper, then a Minister at the Department of Health, set up CERRIE as a Government

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[104] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/337141/HPA-RPD-066_for_website2.pdf

[105] Policy Adviser in the Agency's Radioactive Substances Division and Head of Radioactive Substances Regulation

[106] http://www.llrc.org/campaigns/justification/RResponsetoPWilkinson-final170717.pdf

Advisory Committee on a tripartite model not previously known in Whitehall. Informal discussions with Mr. Meacher and his officials had revealed the embarrassments of the then recent BSE scandal, which followed from mistaken assurances by the Spongiform Encephalopathy Advisory Committee that BSE could not be transmitted across species. CERRIE was intended to avoid such errors by including advocates of alternative views.

LLRC was represented. Meacher laid down a remit of producing a final report agreed by all the committee members to define the essential areas of agreement and explain any remaining areas of disagreement, together with recommendations for research to resolve them.[107] This was not achieved. A member of the secretariat resigned early in the process accusing the chair and another secretariat member of bias and predicting that these problems would compromise the chances of reaching an agreed report. An interim report attracted poor reviews from the invited guests at a three-day international workshop. By then Meacher was no longer a minister.

Drafts for the final report did not represent the full range of views. Anonymously written, they were difficult to amend and a minority of members were reduced to writing dissenting texts, proposing that these should appear in parallel. Two plenary meetings voted to include the dissenting texts with only one member voting against. It was repeatedly said that the dissenting material contained “offensive” and “possibly libellous material” but repeated requests for the offending passages to be identified were never answered.

At the final meeting in June 2004, opinions provided by two departmental lawyers warned that committee members might be found liable if the final report contained libellous material. No such material was identified but a motion to entirely exclude the dissenting statements was carried by four votes to two against with three abstentions including the chair, the remaining two members being absent. The introduction to the official Report repeats the allegations that “the drafts contained possible libellous statements”. These allegations have never been substantiated. A Minority Report was published independently.[108] COMARE's 9th Report, which advised the UK government's Departments on CERRIE’s findings, confirmed that the Majority Report had failed to identify the reasons for the lack of consensus.[109]

8.1.5 An application for a Justification review in 2016

Under EU Basic Safety Standards Directives (BSS), any practice that exposes people to ionising radiation has to be "justified". Justification is a relatively simple cost benefit calculation that weighs health detriment from radiation against the social and economic benefits of the practice in question. The BSS Directives also provide for a justification decision to be reviewed in light of "new and important" evidence about the costs or the benefits, including alternative ways of providing the same benefits; an example would be the availability of cheap renewable energy in sufficient quantities to affect the justification of a nuclear power station.

The governments of EU nation states are responsible for Justification decisions; the European Commission would have a role in determining whether a review had been conducted properly if there were to be dispute about the process (Fn.2 in Appendix 1). BEIS is the relevant Department in the UK.

In 2016, LLRC applied to the Justification Application Centre (JAC) of BEIS for a review of the justification of the Hinkley Point C nuclear power station. The evidence submitted by LLRC was an account of the failings of the LSS study of Hiroshima and Nagasaki survivors as laid out in an exchange of correspondence in *Genetics*, the journal of the Genetics Society of

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[107] http://www.llrc.org/campaigns/testvets/testvettranscripts/BramhallWitnessStatementforTribunalCase.pdf

[108] *CERRIE Minority Report* Sosiumi Press Aberystwyth 2004 ISBN 0-9543081-1-5

[109] https://www.gov.uk/government/publications/comare-ninth-report

America. A nuclear physicist, Dr. Bertrand Jordan, claimed that popular perception of the dangers of radiation is irrational and alarmist and that the LSS should reassure on the civil uses of nuclear power [Fn.3 in Appendix 1]. A reply from Dr. Chris Busby drew attention to the inadequacy of the LSS. Dr. Jordan offered a short response but did not address the criticisms. The application to JAC included the meta-analysis of congenital malformations [Fn.7 in Appendix 1] as an example of evidence that falsifies the ICRP risk factors predictions based on the LSS.

BEIS rejected the application. An exchange followed which is far too voluminous to include in this report. It can be found on the internet and links are in Appendix 1 of this report. Here it must be noted that applying for the review was valuable because the potential involvement of the European Commission induced BEIS to address the application in detail and in writing. [Fn.2 in Appendix 1]. This introduces an element of accountability and distinguishes the process from the usual practice in dialogues encountered by the present authors, which is that little or nothing is committed to paper. LLRC used the opportunity to analyse the BEIS responses and there was a second round of correspondence, the relevance of which will become clear in the next sections, 8.1.6. and 8.1.7.

8.1.6 The Cardiff mud dump

In late 2017, campaigners in south Wales and in parts of England surrounding the Severn Estuary objected to a Marine Licence granted by Natural Resources Wales (NRW), the Welsh counterpart of the Environment Agency in England. The licence allowed EdF, the company building Hinkley Point C, to dredge 300,000 tonnes of mud and rock from the estuary bed and dump it on a shallow sandbank close to Cardiff.[110] Samples of the sediment had been examined for radioactivity by the UK Government-owned CEFAS laboratory and declared safe for disposal. LLRC advised that the testing methods used were inadequate for characterising the degree to which particles of uranium, plutonium and americium were likely to be present and drew attention to UN and other data showing substantial amounts of particulate matter had been emitted from Hinkley Point in the past in addition to radioactivity from other sources.

In evidence sessions in the Welsh Assembly, it was apparent that NRW had no radiological expertise and relied on advice from EA colleagues. LLRC wrote to the Chair of NRW's Board analysing the correspondence relating to the 2016 Justification review and drawing attention to the scientific issues that are common to both. At that time there was a hiatus in the governance of NRW and the correspondence was forwarded to the Environment Secretary in the Welsh Government. Her response was that the scientific issues are for NRW; NRW eventually replied that the matter was for LLRC to discuss with BEIS. The Marine Licence was debated twice in plenary with Assembly Members expressing concern that LLRC's reports were not being adequately considered.

Accepting NRW's advice, the authors of this report, with the endorsement of the Welsh chapter of the Nuclear Free Local Authorities, raised the topic at a meeting of the BEIS Nuclear NGO Forum, and suggested that Joint Fact Finding was an appropriate way forward. They were invited to specify a suitable process for dealing with it. A summary of the situation and an agenda for Joint Fact Finding on relevant scientific issues were presented and discussed at the following meeting of the BEIS Nuclear NGO Forum on 26th January 2019 (Fn[111] and Appendix 1 of the present report).

The JFF proposal document includes references and links to many resources which otherwise should have been included in this report. The resources include detailed forensic analysis of the correspondence with BEIS relating to their rejection of LLRC's application for review of Hinkley Point C. The proposal document summarises this in terms of "... the responses from

[110] The licence expired on 14th March 2019, one third of the permitted volume having been dumped.

[111] http://www.llrc.org/campaigns/justification/BEISjffJAN2019.pdf

the JAC (BEIS), Public Health England, and COMARE are, in various ways, irrelevant, evasive and misleading".

In June 2019 BEIS rejected JFF on the grounds that it would undermine COMARE but instead offered to facilitate written dialogue between the NGOs and COMARE and/or Public Health England. The present position is that the NGOs have accepted the offer and have proposed that COMARE be asked to address matters arising from a letter signed by their Chair in March 2017.

8.1.6.1 A further Cardiff mud dump

The original Marine Licence lapsed in March 2019. As this report was being finalised Natural Resources Wales announced a public consultation on the sampling and testing regime proposed for a second round of dredging and dumping planned, like the first, to enable construction at Hinkley Point C. The new licence is for up to 600,000 tonnes.

8.1.7 BEIS's role in dialogue

The BEIS Nuclear NGO Forum has discussed radiation risk from its inception. There have been meetings with COMARE in 2012 and 2017, each of which was requested by the relevant Minister. In the interim, concerns were raised over the form and content of the 2012 meeting and a more formal Joint Fact Finding process was sought. This has consistently been deflected.[112]

In March 2015, the Minister then representing BEIS in the Forum offered to sponsor NGO involvement in an academic review of the evidence base relating to radiation risk. This was frustrated by lack of information on who would be conducting the review and by communication failures but when the review — an Oxford Martin School *Restatement* — eventually appeared it was of some interest and is discussed here.

8.1.8 Oxford Martin School *Restatement*

In September 2017, *Proceedings of the Royal Society B* published a set of papers on radiation risk in the Oxford Martin School *Restatements* series, which are defined as ".... reviews of the natural science evidence base underlying areas of current policy concern and controversy.".[113]

The Abstract states:

> "The purpose of this restatement is to provide a concise entrée into this vibrant field, pointing the interested reader deeper into the literature when more detail is needed. It is not our purpose to reach conclusions on whether the legal limits on radiation exposures are too high, too low or just right. Our aim is to provide an introduction so that non-specialist individuals in this area (be they policy-makers, disputers of policy, health professionals or students) have a straightforward place to start. The summary restatement of the evidence and an extensively annotated bibliography are provided as appendices in the electronic supplementary material."

Acknowledging that the health effects of low doses or low dose-rates of ionising radiation are unclear it states:

> " … the LNT model and the dose limits are widely debated. Some believe that they are too strict and impose unreasonable costs on the use of radiation. Others believe that they are not strict enough and allow too much risk from radiation exposure."

Having thus defined three distinct views, the Restatement gives two references: an editorial in *Radiology* arguing in favour of hormesis and a parallel editorial in the same issue rejecting

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[112] http://llrc.org/campaigns/muddump/JFFdocs/BaronessVermatoBramhallandWilkinson.pdf

[113] https://doi.org/10.1098/rspb.2017.1070

it.[114],[115] Neither the discussion nor the references includes evidence of greater risk, though there is an extended discussion of papers that argue that there is a threshold.

It may be noted that the *Restatement* [116] illustrates six different dose response curves but omits biphasic. This may be compared with the CERRIE majority report which includes a biphasic curve.(Fn.86 p.19)

The *Restatement* acknowledges that ".... Assessing the risks from internal emitters is particularly difficult"[117] but leaves the scientific debate where it was ten years earlier. In this respect the *Restatement* does no service to its intended audience of "interested readers". By way of contrast, the authors of the present report offer Part 2 *Conflicting risk models* to explain how the differing dose response models can be understood and the apparent contradictions reconciled.

8.2 *Independent World Health Organisation*

On 26 April 2007 — the 21st anniversary of the Chernobyl disaster — a vigil was held in Geneva in front of the headquarters of the World Health Organisation, an agency of the United Nations. The vigil continued every working day for the next ten years, as members of the "IndependentWHO – Health and Nuclear" highlighted WHO's failure to protect populations affected by radioactive contamination. The pickets demanded that WHO should fulfil its autonomous public health responsibilities and stop deferring to the International Atomic Energy Agency (IAEA), which exists to foster the deployment of civil nuclear power. Since after ten years WHO's official stance remained unchanged, IndependentWHO decided to continue its struggle in other ways and the last vigil was held on Chernobyl Day 2017.

From two long interviews at http://independentwho.org/en/videos/ and recent personal communications, IWHO's criticisms can be summarised as:

- WHO lacks expertise and is subservient to the IAEA's pro-nuclear agenda;
- WHO has routinely allowed IAEA to write responses to issues which are properly WHO's remit even when the matters had originally been addressed to WHO;
- WHO's "experts" lack independence; they have often been seconded from industry and latterly they have not been replaced;
- IWHO condemns WHO's 2006 Chernobyl Forum [Fn.71] publication for ignoring genetic effects and for over-emphasising allegedly irrational fears of radioactive fallout;
- IWHO condemns WHO [71] for confining its attention almost exclusively to cancer, and principally to thyroid cancer, despite the fact that all organ systems are affected by radioactive fallout which means that virtually all kinds of illness may result (and *do* result, according to independent research);
- IWHO condemns WHO for restricting its investigation of Chernobyl effects to the most highly contaminated territories (Russia, Belarus, Ukraine) and ignoring effects in other parts of the globe where 57% of the fallout was deposited;
- IWHO condemns WHO for minimising the reporting of congenital malformation;

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[114] Tubiana M, Feinendegen LE, Yang C, Kaminski JM. 2009 The linear no-threshold relationship is inconsistent with radiation biologic and experimental data. Radiology 251, 13–22. (doi:10.1148/radiol.2511080671]

[115] Little MP, Wakeford R, Tawn EJ, Bouffler SD, Berrington de Gonzalez A. 2009 Risks associated with low doses and low dose rates of ionising radiation: why linearity may be (almost) the best we can do. Radiology 251, 6–12. doi:10.1148/radiol.2511080671)

[116] http://dx.doi.org/10.1098/rspb.2017.1070

[117] https://dx.doi.org/10.6084/m9.figshare.c.3838153 Appendix A p.4

- IWHO recognises that the ICRP's Linear NoThreshold model, being based on Japanese survivor data, is appropriate only for acute external high dose exposures and that LNT takes insufficient account of internal radioactivity which accounts for 95% of long-term effects due to internal fallout exposures;
- IWHO is critical of ICRP's lack of expertise in public health, biology, and genetics;
- IWHO says that, in the absence of relevant expertise and independent thought at WHO, the responsibility for precautionary measures lies with UN member states.

IWHO long ago dropped earlier calls for WHO to repudiate a 1959 agreement between WHO and IAEA, [118] reasoning that the agreement never prevented WHO from conducting relevant research. IWHO emphasises the importance of persuading WHO to commission relevant research but recognises that, in addition to its long-term subservience to IAEA, WHO is compromised by a claimed lack of resources and an actual lack of expertise. IWHO says that the real experts are NGOs and self-funded independent scientists.

[118] WHA 12-40 http://independentwho.org/en/who-and-aiea-aggreement/ (NB: spelling in URL)

Part 2

9 Conflicting risk models

The 1943 decision to combine the energy from all kinds of radiation sources into a single dose concept which defines dose in joules per kilogramme (see 1.1) has been incorporated into ICRP's Recommendations. There is general agreement about the effects of exposures greater than 100 millisieverts (40 times UK natural background) but below that dose there is considerable dispute.

9.1 The conventional Linear No Threshold (LNT) view of the ICRP

LNT is an approximation for radiation protection purposes, depicting the idea that the risk of radiogenic disease is in strict proportion to radiation dose. This is why the blue line is straight.

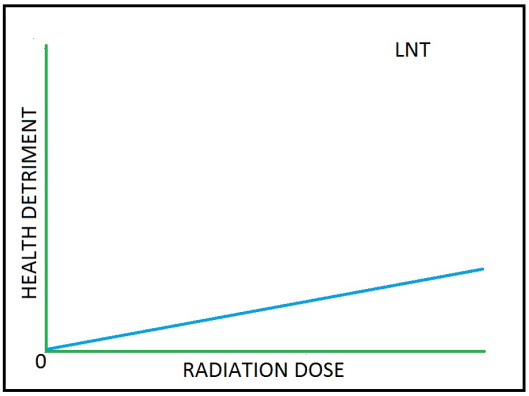

Fig. 5: Linear No Threshold dose response

LNT is a composite of three hypotheses:

1. that there is no dose so small that it cannot cause a biologically deleterious effect (i.e. there is no threshold);
2. that the conventional definition of radiation dose as an average of energy in tissue is scientifically meaningful;
3. that the relationship between dose and effect is strictly proportional (i.e. linear).

These three notions are independent of each other. The first hypothesis is certainly correct. It rests on the observation that the smallest quantum of energy from ionising radiation is a single ionisation; in other words a change in the structure of a single atom. This can be caused by a single radiation track passing through tissue and there is a possibility that the damage will not be adequately repaired and that a genetic change will result, potentially leading to the expression of disease. The dose to the organ or to the whole body would be vanishingly small; the dose to the DNA or to the cell would be massive. This destroys the second hypothesis. The third is implausible for reasons laid out above in discussion of childhood leukaemia and congenital malformation.

Other models have been proposed, some suggesting that risks are greater than LNT suggests, others that risks are lower. In discussions of policy it is common to hear LNT proposed as the sensible middle ground between irrational extremes.

9.2 Biphasic model

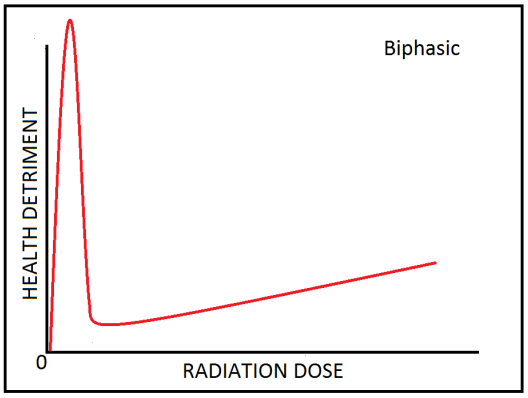

Fig. 6: Biphasic dose response

Epidemiological studies of particular diseases often show an effect rising at low doses, a fall-off of effect at greater doses, and a second rise at still greater doses. This is not what a linear model predicts. An example can be seen in section 6.2.3 above, which examines the association between childhood leukaemia and fallout particles concentrated near high voltage power lines. The cited paper (Fn.65) shows the variation in fallout doses over the years 1962 - 2008 and plots the leukaemia rates. The relevant part of the graph is reproduced here.

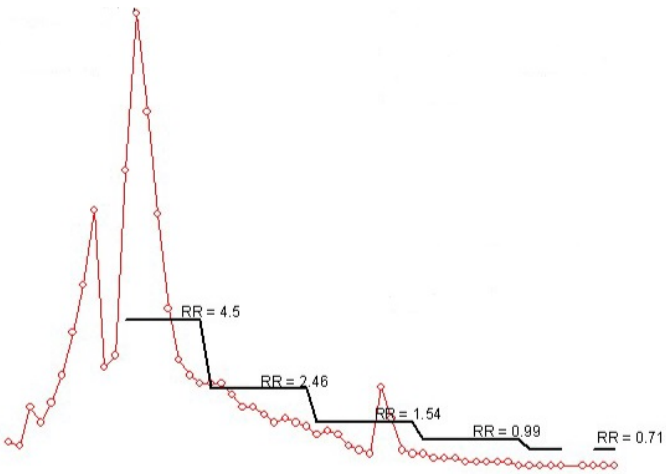

Fig. 4a: a real-world biphasic dose response

The brown line shows the annual doses from the fallout in UK calculated by NRPB. The two tall peaks on the left show the fallout doses from two particularly intense episodes of testing in 1959 and 1963. The small peak right of centre is Chernobyl's fallout. The black line is the excess rate of childhood leukaemia. It appears to be stepped because the data are given in 10-year blocks. The point of interest here is that the greater levels of fallout dose in the first period, 1962-1969, appear to be less efficient at causing leukaemia than the later, smaller levels. It may be noted that the rate of change in the disease is greater when there is a greater rate of change in the dosage but the risk per unit dose is smaller. This is clearer in the table below. It is not what the conventional model predicts, since that assumes linearity.

Period	1990-'99	1980-'89	1970-'79	1962-'69
Annual dose	6 microSv	12 microSv	20 microSv	64 microSv
Relative Risk	1	1.5	2.5	4.5

Apologists for the nuclear industry use this phenomenon to suggest that the fallout is not the cause of the disease, e.g. as expressed in the 2014 Wakeford document (see Fn 9), but overlook the widespread change in infant mortality which occurred at the same time, as discussed in section 6.2.2 and illustrated in figure 3 on page 25.

The paper (Fn.60) from which the figure is taken, has similar figures for stillbirths, first day deaths, and deaths within the first 28 days. They all show that, as soon as the weapons testing began, the underlying trend of improving infant survival was reversed. The present authors have not been able to ascertain how many of the dead babies who fill the spaces between the dotted lines and the trend were diagnosed with leukaemia. It surely would have been a very small proportion of those who were stillborn or died within 24 hours but the point is that leukaemia might have been diagnosed if the child hadn't died so young. Alice Stewart, who studied child leukaemia for decades and showed that pre-natal X-rays caused leukaemia (section 6.2.1), pointed out that pre-leukaemic conditions reduce the competence of the child's immune system so that "competing causes of death" are often fatal before the leukaemia can be diagnosed.[119] Thus epidemics of infectious diseases are accompanied by falls in the leukaemia rate, and even the prevalence of colds in winter may make it seem that cold weather protects children from leukaemia. There is no conflict between the idea that infections act as competing causes of death and the idea that higher radiation doses do the same thing.

As noted in 6.2.4 however, another example of a biphasic dose response is apparent after the Chernobyl accident, when congenital malformations were more frequently registered in low contamination zones than in high. In this case infections as a competing cause of death cannot be invoked. The phenomenon was explained by the authors (Fn.69) in terms of the higher levels leading to greater levels of internal exposure and hence increasing damage to various critical stages in foetal development, increasing the likelihood that the pregnancy would fail either early or late. There would be a consequent fall in birth rate which was actually observed. Only the survivors would be recognised as malformed and appear in the statistics. In contrast to leukaemia, infections would be unlikely to have a significant impact on registrations of congenital malformation.

9.3 Hormesis model

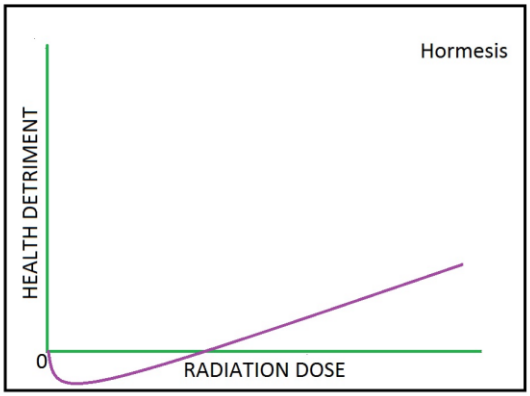

Fig. 7: Hormetic dose response

Some people think low doses cause health benefits, as represented by the section of the purple line in Fig.7 that lies below the horizontal axis. This opinion is based largely on laboratory studies of radiation, most of which use cell cultures exposed to gamma or X-rays and appear to induce an increased ability to repair cellular damage, so-called *adaptive responses*.[120] "Low dose" in this context is defined as "below 200 milliSieverts".[121] The

[119] "The Woman Who Knew Too Much: Alice Stewart and the secrets of radiation"; Gayle Green, U. Michigan Press 1999 ISBN 0 472 08783 5 p.233 et seq.

[120] For an outline see *Radiation Hormesis: Historical and Current Perspectives* Baldwin J, Grantham V. J. Nucl. Med. Technol 2015 http://tech.snmjournals.org/content/43/4/242.full

processes occur naturally and repair damage from processes unconnected with radiation — reactive oxygen species, for example. The protective effect is claimed to equal or outweigh damage from low doses of radiation but decreases at doses above 100 - 200 milligray and is not observed after acute exposures above 500 mGy.[122]

It is claimed that the benefits in the cell studies are also seen in epidemiological studies, notably of inhabitants of apartment blocks in Taiwan that had been built using reinforcing bars contaminated with Cobalt60.[123] Results are equivocal and the Taiwan study is of low quality because a substantial proportion of the people who had lived in the apartments had moved away or died and information on their health was not available. Nevertheless, some proponents of hormesis believe that current radiation protection standards based on ICRP and LNT should be relaxed because they impose unnecessary costs on the nuclear industry and that relocating populations after disasters causes more suffering and deaths than are caused by the radiation. It has been reported that US policy makers looking at the costs of Department of Energy radioactive waste sites created a research programme to study low-dose radiation. By 2003 nearly $100 million had been spent in the first 7 years, mostly on in vitro cell studies.[124]

Proponents of hormesis tend to blame the prevalence of the LNT model for making people afraid of radiation, reducing their willingness to undergo its therapeutic and diagnostic uses. Dr. Boulton's paper (Fn.18) echoed the Académie Nationale de Médecine on this point (Fn.25).

9.4 Threshold model

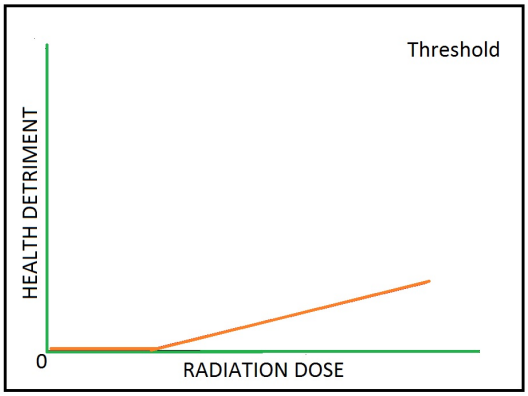

Fig. 8: Dose response with a safe threshold

Some people argue that doses below 100mSv can be disregarded on the grounds that epidemiology doesn't show health damage that can unequivocally be attributed to radiation.[125] This belief is based on the observation that at those doses there is not a consistent linear dose response, which ignores the logic of biphasic effects caused by deaths before diagnosis and the inevitable logic underlying the "no threshold" hypothesis

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[121] *It Is Time to Move Beyond the Linear No-Threshold Theory for Low-Dose Radiation Protection* John J. Cardarelli II and Brant A. Ulsh: Dose Response. 2018 Jul-Sep; 16(3): https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6043938/ [The paper gives "generally … below 200 mGy" as defining "low dose", which is equivalent to 200mSv in the context of the X- and gamma-ray exposures that most hormesis experiments use.]

[122] Evidence for beneficial low level radiation effects and radiation hormesis: L E Feinendegen 2014 https://doi.org/10.1259/bjr/63353075

[123] Hsieh WH, Lin IF, Ho JC, Chang PW (2017) 30 years follow-up and increased risks of breast cancer and leukaemia after long-term low-dose-rate radiation exposure. Br J Cancer 117: 1883–1887.

[124] Kaiser J. Hormesis: a healthful dab of radiation? Science 2003;302(5644):378.

[125] e.g. Antony Hooker of the Environment Protection Authority of South Australia — see https://link.springer.com/article/10.1007/s13246-011-0097-x

incorporated in LNT. It is a simplistic and mechanistic view and a case of believing that absence of evidence is evidence of absence.

To put the 100mSv dose figure into context, the limit for workers in the UK nuclear industry is 20mSv per year and this is the same figure being used by Japanese authorities in deciding whether evacuees should return to towns and farms contaminated by the Fukushima disaster. As with Hormesis, the Threshold hypothesis is often used to promote the idea that people suffer less from radiation than from needless anxiety about it and from accidents, stress and grief associated with relocation.

9.5 Can the models be reconciled?

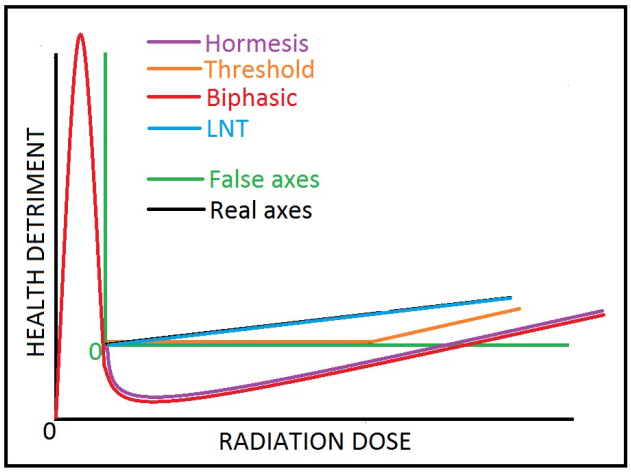

Fig. 9: Which zero dose axis is real?

This figure is offered as a way of understanding how rational people can hold such widely differing views.[126] First it must be said that there is a larger number of theories on dose response curves than these four - for example CERRIE[127] and the Oxford Martin School *Restatement* [128] each show six (though not the same six, since the *Restatement* omits biphasic) - but the four categories discussed above cover the range of opinion.

The Biphasic (red) and Hormesis (purple) curves have common ground in that both are based on evidence and on scepticism about the theoretical basis of the LNT. There are, however, questions about the reliability of the claimed epidemiological basis of Hormesis, as outlined above, and about extending cell culture observations to living creatures. Biphasic and multiphasic effects were observed in cell cultures by a Russian Academician, the late Elena Burlakova, who did not regard them as evidence of any protective phenomenon.[129] A biphasic dose response apparent in epidemiology is in Figure 6, which plots leukaemia in human infants reported in various studies across Europe after Chernobyl. Other examples cited in this report are congenital malformations after Chernobyl, child leukaemia in the weapons test period and child leukaemia in relation to nuclear installations in England and Wales.

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[126] The figure is based on a sketch by Chris Busby.

[127] https://webarchive.nationalarchives.gov.uk/20140108135440/http://www.cerrie.org/pdfs/cerrie_report_e-book.pdf p.19

[128] https://doi.org/10.1098/rspb.2017.1070

[129] Burlakova, E.B; Goloshchapov, A.N; Zhizhina, G.P.; Konradov, A.A. New aspects of regularities in the action of low doses of low level irradiation. In *Low Doses of Radiation—Are They Dangerous?* Burlakova, E.B., Ed.; Nova Science Publishers: New York, NY, USA, 2000.

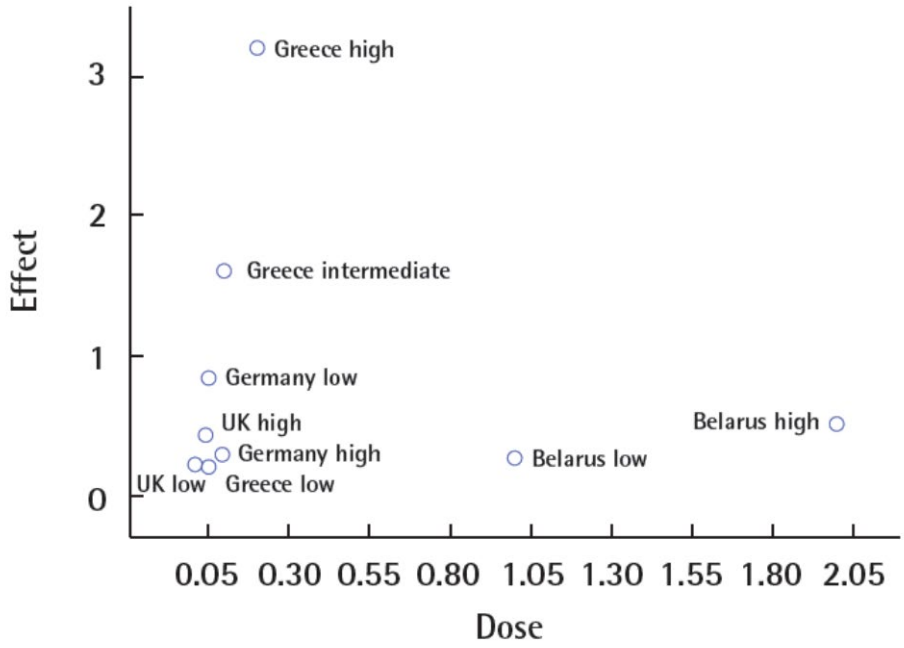

Fig. 10: A real-world biphasic effect: infant leukaemia across Europe after Chernobyl: source as Fn.69 Doses are in millisieverts. The source paper identifies the "Effect" units as "Fractional excess relative risk". The values can be multiplied by 100 and understood as "percentage increase relative to expected in the absence of the exposure to radioactivity". ("High, "low", and "intermediate" refer to doses. The present reader is invited to join the dots in the order of the increasing doses to derive a dose-response curve; use of setsquare and ruler recommended. A Burlakova curve can be discerned at around 0.05 mSv, though this may be due to uncertainty in the data).

In Figure 9, the Hormesis and Threshold curves converge at roughly 100mSv, which is five times the annual nuclear worker dose limit in the UK. This is the dose at which proponents of the Threshold hypothesis accept that there is evidence of harm. It may be noted that Hormetic effects are claimed for doses above 100mSv but it was necessary not to overcomplicate the graph. The supporters of Hormesis and Threshold believe the ICRP's assumption that there is no threshold is excessively cautious and that the consequent drive to reduce exposures in the low dose region is crippling the nuclear industry.[130] The difference between Threshold and Hormesis is that the Hormesis proponents may accept that the physical mechanism of radiation damage means there can be no ***actual*** threshold, but they believe adaptive responses provide an ***effective*** threshold.

The Biphasic curve coincides with Hormesis because they are describing the same health data; the difference is in interpreting its significance. Hormesis proponents mistake the curve below the axis for radiation-induced repair and this is because the green horizontal axis is in the wrong place; the true dose axis is the black horizontal one. The space between the green and the black horizontal axes represents ***invisible dose*** — "invisible" because LSS has data only for external dose and ignores the effect of uranium fallout (discussed in section 6.1). Similarly, the large "INWORKS" studies of nuclear workers [131] which are thought to confirm the LSS make the same error as the LSS since they use the lowest dose workers as a control although the group includes people with recorded doses. The lowest dose workers

[130] e.g. Radiation and Reason: The Impact of Science on a Culture of Fear: Wade Allison York Publishing Services (2009) ISBN: 0-9562756-1-3

[131] Lancet Haematol. 2015 Jul;2(7):e276-81. Ionising radiation and risk of death from leukaemia and lymphoma in radiation-monitored workers (INWORKS): an international cohort study. Leuraud K, Richardson DB, Cardis E, Daniels RD, Gillies M, O'Hagan JA, Hamra GB, Haylock R, Laurier D, Moissonnier M, Schubauer-Berigan MK, Thierry-Chef I, Kesminiene A.

mostly work on contaminated sites and may have inhaled radioactive particles, like the survivors at Hiroshima and Nagasaki. The LSS survivors should have been compared with inhabitants of other cities; the nuclear workers (all of them) should be compared either with workers of similar employment status in an industry where there is no radioactivity or with the national population, adjusting for the Healthy Worker Effect.

The space between the green and the black vertical axes represents ***invisible effects.*** They are invisible because they are ignored, largely because of the linear dose-response assumption (*WHO Chernobyl Forum* cited in section 6.2.4 above is a typical example). The downward slope is due to loss of data from competing causes of death as discussed in 9.2. There is more discussion of this topic in the exchange of letters in *Genetics* at Fn.55

9.6 The scale of the discrepancy

As we observed in the Introduction, radiation doses from industrial or military discharges are, as conventionally assessed, thousands of times too small to have any discernible effect on rates of disease. The Chernobyl disaster provides an opportunity to test this, as noted by the authors of the meta-analysis of congenital malformations (Fn.69). There are large discrepancies between the numbers recorded in official registries and what would be expected on the basis of multiplying the assessed radiation doses by the ICRP risk factor for genetic effects. All the studies show conditions at least 10,000 times greater than ICRP would predict. For example, the number of Neural Tube Defects in the Ukraine after Chernobyl was over 11,346 times greater than predicted[132] while the number of malformations in Belarus was 49,000 times greater[133] —the largest discrepancy identified in the meta-analysis. The method of calculating these numbers is shown in correspondence between the LLRC and BEIS [134] and has not been repudiated; BEIS merely claimed that they could not replicate it. Discussion of the regulatory implications of such an error in risk estimation (9.7 below) uses a collective figure of 10,000 which is at the low end of the range observed in the various studies.

For the sake of putting some context around these large numbers it should be noted that, in discussing childhood cancers and nuclear power stations, Fairlie (Fn.7) has set the discrepancy at between four and five orders of magnitude — meaning that the officially recognised radiation doses are between 10,000 and almost a million times too small to explain the number of cancers observed. COMARE's 17th report [135] includes a discussion which accepts the size of the discrepancy but rejects the hypotheses Fairlie proposes to explain it.

9.7 Regulatory implications

The UK Environment Agency requires that licensed releases of radioactivity cause a maximum of one "health detriment" per year per million people. This risk level was identified in the 1980s by research for the UK government on the health impacts of nuclear power stations. Risks from many activities including mountaineering, scuba-diving, travelling, and having babies were quantified and compared. The research found that people thought a risk of one death per year per million people was a trivial level of risk that they would not spend any of their own money to reduce. This is reported in a still-current HSE publication known as R2P2 — *Reducing Risks, Protecting People.*[136] The "deaths" standard

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[132] https://doi.org/10.1542/peds.2009-2219 and https://doi.org/10.1111/cga.12051

[133] Changes in registered congenital anomalies in the Republic of Belarus after the Chernobyl accident: Stem Cells 1997; 15(supp12):255-260 G. I. Lazjuk D. L. Nikolaev I. V. Novikova https://doi.org/10.1002/stem.5530150734

[134] http://www.llrc.org/campaigns/justification/LLRCtoJAC22052017.pdf

[135] Committee on Medical Aspects of Radiation in the Environment (COMARE) 17th report: review of childhood cancer incidence near Sellafield and Dounreay from 1963 to 2006 ISBN 978-0-85951-785-0 30 September 2016. See paragraph 5.76 onward.

[136] Reducing Risks, Protecting People http://www.hse.gov.uk/risk/theory/r2p2.pdf. See also http://www.onr.org.uk/documents/tolerability.pdf

has since been modified to "health detriments", defined as fatal cancer, non-fatal cancer and congenital effects.[137] The annual dose figure which the Environment Agency believes to comply with the one in a million threshold of concern is 20 microSieverts. However, as discussed in 9.6 above, calculations based on the evidence summarised in the present report show that releasing radioactivity at that 20µSv level causes health detriments not at a rate of one in a million but at one per cent —a 10,000-fold difference.

PART 3 Understanding the discrepancy

10 Conceptual errors

It is not suggested that every kind of radiation exposure is 10,000 times more dangerous than it appears according to current risk factors.

As outlined in section 5 above, the discrepancy arises from the conceptual error made in 1943 when direct observation of the biological effects of specific contaminants inside the body was abandoned in favour of estimating risks on the basis of the average energy from all radiation sources. The apparently scientific precision of the resulting dose quantities was reassuring and the idea that they could be added together to give a single value to define a risk unit for all kinds of exposure was administratively convenient. However, many assumptions had to be made to accommodate the fact that different kinds of radiation vary in the amount of energy they impart to tissue, and in the spatial distribution of ionisations within tissue and even within individual cells. Cells also have highly differentiated internal structures which are not all equally sensitive. These assumption have always been contentious and this has added to the uncertainties caused by failing to examine all the relevant epidemiology, as described above.

10.1 Over-simplification of a complex issue

The most abiding feature of the long debate about radiation risk is the tendency to over-simplify complex scientific issues. A notable example was seen during the popular campaign against the Cardiff mud dump [see 8.1.6 above]. The main thrust of the anti-dumping campaign was the fact that the mud is known to contain respirable particles of anthropogenic uranium, plutonium and americium. In response, EdF sent Welsh Assembly members a briefing comparing radiation doses from radioactivity in the mud with exposure to cosmic rays during high-altitude air travel, radon gas in homes, and the small proportion of the potassium in bananas that is naturally radioactive. Banana Equivalent Dose is briefly addressed in a footnote.[138] Beyond that, it is not necessary to go into detail about the wide differences between the exposures EdF referred to; the essence is that EdF was putting the emphasis onto average dose and ignoring all the evidence that informed the caution of, for example, COMARE's Second Report (section 3.1) and the complexities of "Microdosimetry".

10.2 Microdosimetry

The CERRIE report (See Fn.32) offers this working definition of microdosimetry:-

> "….the study of the physical microscopic properties of ionising radiations, their interactions and their patterns of energy deposition, with particular emphasis

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[137] Modelling radionuclide transport in the environment and calculating radiation doses M. Thorne, in Radionuclide Behaviour in the Natural Environment, 2012 https://www.sciencedirect.com/topics/engineering/relative-biological-effectiveness

[138] The present authors are aware of nothing about Banana Equivalent Dose in the scientific literature and believe this is because it is not something any journal would consider. It would not be worth mentioning here but for the fact that some elected representatives in Cardiff read EdF's briefing, with its assertion that annual doses from the mud dump would be less than the dose received from eating 20 bananas, and used it to ridicule those who were expressing concern about uranium particles. A competent journalistic treatment of BED is at https://boingboing.net/2010/08/27/bananas-are-radioact.html

on the inhomogeneities and stochastic nature of the interactions. This is in contrast to conventional dosimetry, which is based on average macroscopic quantities such as absorbed dose. In many situations absorbed dose is totally inadequate to describe radiation action in biological, or other, material because the mechanisms and effects are dominated by the inhomogeneous microscopic properties, especially at cellular or subcellular dimensions"[139].

The report also states:[140]

> "The linking of biological effects to track structure is one of the central research goals in the field of microdosimetry."

10.3 High and Low Energy Transfer

The best-known aspect of microdosimetry is "Linear Energy Transfer" (LET) which refers to the number of ionisations per unit length of the path (or "track") that a subatomic particle takes through any medium. For radiation protection purposes LET is confined to two broad categories — "high" and "low" as illustrated below in figure 11. Low LET gammas, which are photons, have no electric charge and virtually no mass and travel at close to the speed of light. These factors mean that gammas interact with matter and cause ionisations relatively rarely, which explains why they are highly penetrating and why large thicknesses of dense materials are needed to shield people from the radiation produced in nuclear reactors. At the opposite end of the ionising radiation spectrum, alphas are the nuclei of helium atoms. Compared with gammas, they have massive momentum and very large cross section. They therefore interact with matter intensely, giving up their energy in the form of large numbers of ionisations and slowing down so rapidly that they cannot penetrate the layer of dead cells on human skin. The difference between Low LET and High LET radiation tracks may be illustrated using the analogy of a rifle bullet, a 40 ton truck, and a pottery warehouse. It is quite possible for the bullet to traverse the whole building without breaking any crockery and go on to kill a cow in the next parish, but the truck inevitably and swiftly grinds to a halt as shattering dinner sets absorb its momentum.[141]

10.4 Radiation Quality explained by Professor Goodhead

The differences between Low and High LET are addressed in a topic called Radiation Quality (RQ). Discussion of this will rely on material by Professor Dudley Goodhead who is a leading expert on radiation track structure at the atomic, molecular and cellular levels and on the impact of those considerations for radiobiology and health.[142]

A detailed discussion of RQ is far beyond the scope of this report and it seems that even radiation protection professionals have a weak understanding of the topic (see 10.5). It is necessary to consider its implications.[143] Professor Goodhead has described "the whole system of absorbed dose, tissue weightings and Relative Biological Effectiveness (RBE)" as a

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[139] Goodhead DT (1987). Relationship of microdosimetric techniques to applications in biological systems. In: *The Dosimetry of Ionizing Radiation,* Volume II (eds KR Kase, BE Bjarngard and FH Attix). Academic Press, New York, pp 1–89.

[140] CERRIE report para 14

[141] The authors acknowledge that the truck analogy fails to convey the reality of the Bragg peak which means ionisations are most densely packed just before a radiation track stops (this is the basis of proton beam cancer therapy). They would be happy to consider suggestions. The analogy does however accommodate the delta rays illustrated in Fig.7, which can be visualised as packing cases thrown aside by the truck and causing collateral damage to other structures.

[142] http://www.icrp.org/docs/Goodhead - 15th Gray Medal-Final.doc

[143] Committee Examining Radiation Risks of Internal Emitters; Majority report Part 2.2 https://webarchive.nationalarchives.gov.uk/20140108135440/http://www.cerrie.org/pdfs/cerrie_report_e-book.pdf

"complex, yet crude, system to achieve additivity of risk from all exposures" which is "Convenient for rough planning purposes in radiological protection" (emphasis in original).[144]

The image and description below are included in this report as a counterpoise to simplistic accounts of radiation exposure and the suggestion (as mentioned above) that radiation doses from environmental contamination are scientifically precise and well characterised.

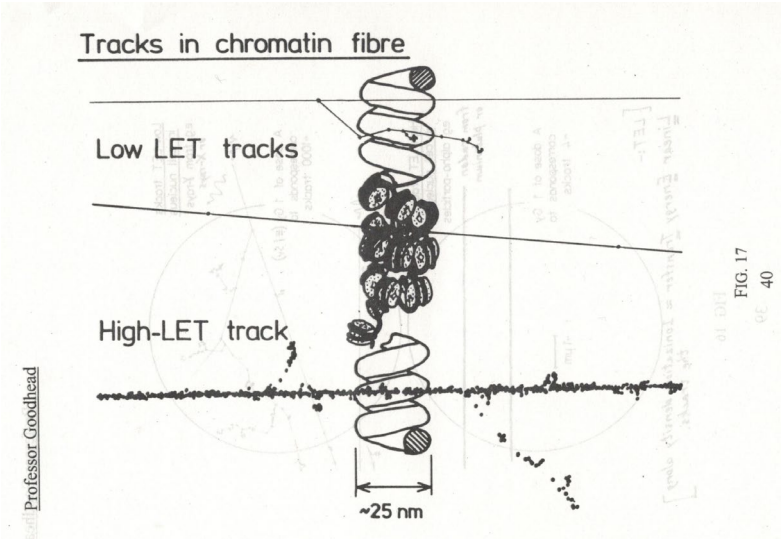

Fig. 11 *Radiation Quality.* Tracks in chromatin fibre: illustration from Professor Goodhead's presentation at a meeting in the House of Commons in 1996.[145] The change in the chirality/ handedness of the chromatin spiral is anomalous but can be ignored.]

Fig. 11 is a simple illustration of different *Radiation Qualities* and their interaction with DNA. The spiral structure shown is not the famous DNA double helix, but a larger-scale organisation called chromatin. As Fig 11 shows, the fibres are 25 millionths of a millimetre in diameter — roughly ten times the diameter of DNA itself.

The manner in which several feet of DNA are organised in every cell in the body is relevant. The DNA is packed into chromatin, and the chromatin is itself packed into chromosomes, of which most human cells contain 23 pairs. The structural hierarchy is illustrated in Appendix 3. Figure 11, which illustrates a radiation track damaging a chromatin fibre, shows the intermediate structures. The dark yoyo-shaped structures represent nucleosomes[146] which consist of DNA wrapped around groups of histone proteins.

Also shown are tracks of three subatomic particles — two Low LET, one High LET. Speaking about this slide in 1996 Professor Goodhead said " … those tracks, if they pass through the DNA, might cause an ionisation within it or they might pass right through without doing anything or they might even cause a little cluster of ionisations which would damage the DNA more seriously. A good deal is known about such processes."(145 p.38) He went on say that any ionisation occurring on or close to DNA has the potential to break both DNA strands which the cell would have difficulty repairing and might well lead to mutation.

Professor Goodhead, who is an authority on RQ, has used the Fig. 11 slide in other presentations, for example in a European Union Scientific Seminar in 2007[147] and another in

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[144] http://www.melodi-online.eu/DoReMi/files/Meetings/Radiation quality workshop/02 What is radiation quality Goodhead.pdf *What is 'radiation quality?* Dudley T Goodhead Medical Research Council, UK DoReMi Radiation Quality workshop Brussels. 9-10 July 2013. Slide 11.

[145] "The Health Effects of Low Level Radiation; Proceedings of a Symposium at the House of Commons, London 24 April 1996" Green Audit Books 1997 ISBN 1 897761 14 7

[146] https://www.genome.gov/genetics-glossary/Nucleosome

[147] https://ec.europa.eu/energy/sites/ener/files/documents/the_relevance_of_dose_for_low-energy_beta_emitters.pdf (2007) slide 6.

2013 (Fn.144). For copyright reasons the later figures cannot be used here. In 2007 he added an arrow pointing to the second particle track, drawing attention to the two dots on the track. They are present in the original but are so small that the viewer might fail to notice them; the arrow makes it clear that they represent ionisations. The track at this point has clearly damaged the chromatin fibre and the viewer can infer that there is another ionisation which unfortunately is invisible in the clutter of dark yoyo-like structures which represent disrupted nucleosomes. A second new arrow pointing to the lowest of these nucleosomes indicates the DNA strand.

The bottom of the figure shows the High LET track of an alpha particle. The ionisations occur densely along its length. In addition, the figure shows branching tracks. These represent delta rays, which are electrons resulting from the ionisations created by the alpha itself. Some delta rays have enough energy to cause further ionisations. The figure shows no damage to the chromatin from either the alpha track or the deltas. This may be thought counterintuitive and perhaps even disingenuous; in his 2007 presentation Professor Goodhead added "An alpha-particle has a low probability of hitting DNA (because there are few tracks per gray) but a high probability of damage when it does hit."[148] Pr. Goodhead's explanation that an alpha hit is a "low probability" event "because there are few tracks per gray" is an expression of the high energy density of an alpha track.[149] (2007 presentation slide 6) This is to be compared with the actual topic of his presentation, which was the soft beta emitter tritium which delivers many tracks per gray.

The probability of an alpha track hitting DNA should be considered in light of the evidence referred to in this report showing that DNA has a high chemical affinity for the alpha emitter uranium.

The CERRIE majority report expresses the same idea in terms of High LET radiation having "a greater propensity to cause a concentration of damage within biological molecules; such damage to DNA, including simple and complex double-strand breaks, is more difficult to repair. It has the propensity to cause mutations and chromosomal rearrangements and hence contribute to carcinogenesis and other adverse effects of radiation."

Dose averaging always had its critics and is now, in light of epidemiological evidence, demonstrably inadequate. R. H. Mole's reservations about averaging alpha-particle doses [150] were restated by the Committee Examining Radiation Risks of Internal Emitters in 2004:—

> "There are important concerns with respect to the heterogeneity of dose delivery within tissues and cells from short-range charged particle emissions, the extent to which current models adequately represent such interactions with biological targets, and the specification of target cells at risk. Indeed, the actual concepts of absorbed dose become questionable, and sometimes meaningless, when considering interactions at the cellular and molecular levels."[151]

Professor Goodhead, in slide 5 of his 2007 presentation (147), points out that a single alpha radiation track can deliver between 0.2 to 0.5 Gray to a cell nucleus. Elsewhere [152] he writes "half a gray should not be regarded as a low dose and no-one would normally receive such a single dose except in some situations of radiotherapy or severe radiation accidents". By

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[148] Fn.147 Slide 6

[149] Note that the cell dose from a single alpha track has been quantified at between a fifth of and half of a Gray.

[150] see 3 Hot particles Alpha-emitting particles above

[151] CERRIE Majority Report https://webarchive.nationalarchives.gov.uk/20140108135440/http://www.cerrie.org/pdfs/cerrie_report_e-book.pdf Chapter 2.1 paragraph 11.

[152] https://www.sciencemediacentre.org/expert-reaction-to-study-looking-at-low-doses-of-radiation-and-blood-vessel-cells-in-a-dish/

contrast ICRP models that dose as energy averaged across an entire organ, representing an infinitesimally small increment.

10.5 Relative Biological Effectiveness (RBE)

In light of these considerations, the discrepancy between the number of congenital malformations expected after Chernobyl and the number actually observed, which was between 15,000- and 50,000-fold and has been expressed in other parts of this paper as "a ballpark figure of 10,000", appears unsurprising. But it significantly contradicts the predictions of the conventional radiation risk model. To understand this, it is necessary to look back at the first paragraph of this section where reference was made to "assumptions [that] had to be made to accommodate wide differences in the amount of energy imparted to tissue by different kinds of radiation, in the density with which the energy is distributed in tissue, and in the sensitivity of different parts of cells." The main tool for accommodating the wide differences is Relative Biological Effectiveness (RBE). It is part of what Professor Goodhead called a "complex, yet crude, system to achieve additivity of risk from all exposures".

RBE is a multiplier used to modify physical dose in Grays (which is real, the gray being a measurable quantity defined in joules per kilogramme) turning it into an "Effective Dose" in sieverts (which is a large area of approximation). Gamma rays are the baseline for calculating RBE and axiomatically have an RBE of 1; alphas have an RBE of 20, which according to ICRP is on account of their greater destructive power. But a far larger figure is implied by the real numbers of congenital malformations — 15,000- to 50,000-fold greater than predicted by ICRP.

Part of the explanation of why the RBE of alphas is as low as 20 is that alpha irradiation is so intense (as illustrated in Fig.11) that cell killing predominates, and dead cells have no biological effectiveness because they do not replicate, so a multiplier is required only for the fraction of cells that survive. That's the theory; the real-world evidence of congenital malformations suggests that the cell-killing fraction is massively wrong. It is nevertheless commonplace to see Effective Doses presented as scientifically reliable quantities. An example is the pie chart below and the presumptuous nature of the text that accompanies it. [153]

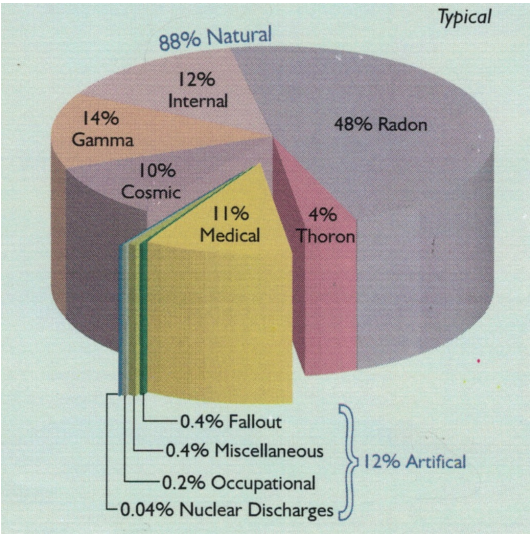

Fig. 12: Pie chart including natural, medical, military and industrial sources based on a web page of the World Nuclear Association

The World Nuclear Association in page shows doses in milliSieverts — the unit that incorporates the questionable Effective Dose 20-fold multiplier. The outstanding point is the large slice — 52%— attributed to radon gas, including the pink slice labelled "thoron", which is an isotope of radon. Radon is an alpha emitter and the 20-fold RBE multiplier has therefore been applied. Radon is one of the elements produced by the decay of uranium in

[153] World Nuclear Association - fromhttp://www.world-nuclear.org/uploadedFiles/org/Features/Radiation/4_Background_Radiation%281%29.pdf

the earth's crust. It is certainly injurious in high concentrations but, apart from a tendency to be absorbed into fat, it is biologically inert and has no capacity for bio-accumulation. It is unlike uranium because it has no affinity for DNA and because, being a gas, it does not occur as particles. So the 20-fold RBE multiplier for radon is not justified; it is, however, convenient for pro-nuclear interests as it diminishes the size of all the other pie slices. Conversely, uranium's chemical affinity for DNA and its interaction with the natural gamma field, which is independent of and additional to uranium's intrinsic radioactivity, confers a significant RBE because it creates a mechanism to locate ionising events on or close to DNA molecules. The RBE of this mechanism is quantified not by theory but by real events such as the weapons tests and Chernobyl which injected tons of uranium into the biosphere. The post-Chernobyl genetic effects suggest that that type of exposure should carry an RBE of four orders of magnitude. The pie chart would look like this:

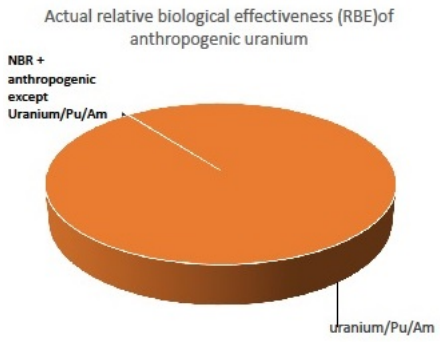

Fig. 13: The actual Relative Biological Effectiveness of particulate uranium. All the contents of the pie chart in Fig. 12 are inside the narrow segment at upper left

10.6 Expert ignorance - "Let's start at the very beginning …"

It was stated above (see 10.4) that Radiation Quality is not well understood by radiation protection professionals. This refers to a presentation given in 2013 by Professor Goodhead to a seminar of the European *Low Dose Research* network ("DoReMi")[154] where, incidentally, he again used the illustration in figure 11. The slides are online [ref.144 above]. They show Goodhead asking his colleagues the basic question of what Radiation Quality means and receiving "many *ad hoc* answers" which reveal a poor understanding of the RQ concept. He quoted definitions of RQ from various medical and scientific/technical dictionaries which differ widely from RQ as he set it out in his presentation, and he found no clarity in publications of the ICRP or the International Commission on Radiation Units and Measurements. Alluding to the fact that the workshop was held under "DoReMi" auspices, he quoted the lyrics of the song of that name from *The Sound of Music*:- "Let's start at the very beginning, A very good place to start …".

10.7 Regulatory ignorance

In 2018 one of the authors of this report drew attention to the lack of information on uranium, plutonium and americium in the material that was to be dumped at Cardiff and applied to the four environment agencies in the UK asking what data they held on particles, with specific reference to marine sediments. The four UK environment agencies reported to LLRC that all the information on uranium was fed through to annual reports on Radioactivity in Food and the Environment (RIFE).[155] The responses showed that the agencies know nothing of the fine particles - only the very much larger ones that the site operators can find with the Groundhog machines they deploy on the foreshore near Sellafield and Dounreay to

[154] European *Low Dose Research towards Multidisciplinary Integration* (DoReMi) network of excellence https://www.irsn.fr/EN/Research/Research-organisation/Scientific-collaboration/DOREMI-network/Pages/DoReMi-network.aspx

[155] https://www.food.gov.uk/research/radioactivity-in-food-and-the-environment

detect and scoop up radioactive debris. The image on page 32 of this report is relevant. The particle which made that impression is between 100 and 200 times smaller than the smallest particles detectable by Groundhog. Groundhog technology is limited by its sensitivity to the gamma signal of Americium, exacerbated by absorption of the radiation ("shielding") if the particle in question is overlain by mud, sand and water. The lower limit is around 200 microns, and such particles are around 10 times too large to be resuspended and inhaled. Ingestion is the main radiological hazard associated with this size of particle; others are the possibility that they become trapped under fingernails or toenails or are absorbed in cuts and grazes. Such hazards are well understood but the inhalation hazard is not, because of the spurious "average dose" approach, and it is common to see official risk agencies claim that the quantities of fine particulates that would have to be inhaled to confer a significant radiation risk would cause a person to choke.[156]

10.8 Wave action and re-suspension

A further consideration is that wave action reduces particle size. This is recognised in NRPB references which were included in LLRC's letters to Welsh Government in 2018.[157] Three mechanisms follow from the reduction in particle size:

1. it is inevitable that an increasing fraction of any given mass of material will become capable of being resuspended and inhaled;
2. the finer particles will travel further;
3. Some of the energy from radioactive decay of atoms inside a particle is absorbed by the particle itself; the larger the particle the greater the proportion of radiation that fails to escape.

Counterintuitively, these mechanisms mean that the inhalation hazard will become greater over time. The Welsh Government has not responded to this information, and their advisers Natural Resources Wales have responded only by recommending that LLRC should take all their concerns about radiation risk back to the Westminster government. As noted above, negotiations with BEIS are continuing while NRW have just announced consultation on a new round of mud dumping.

10.9 Urgent need for a thorough forensic review

The authors of this report are unaware of any discussion of microdosimetry intended for a lay public, even in books by noted critics of the ICRP risk model. In fact Professor Wade Allison, whose 2009 book "Radiation and Reason"[158] argues that ICRP over-estimates risk, acknowledged the importance of microdosimetry but claimed that lack of space prevented him from addressing it [his page 112]. More recently Jorgensen's "Strange Glow", written by a professor of radiation medicine, omitted microdosimetry at his publisher's insistence[159] while science journalist Fred Pearce, whose 2018 "Fallout" has a well-populated index entry oxymoronically named "radioactive dose" concludes, on the basis of no evidence, that he has "come to believe that the threshold argument makes scientific sense".[160] Paul Zimmerman is an exception to this general lack of discussion. He writes in *A Primer in the Art*

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[156] The dominance of "choking hazard" from inhaled particulates over the radiation risk they confer appears to have been floated by the Royal Society in "The health hazards of depleted uranium munitions" Part II 2001.

[157] *"Health Risks from Radioactive Objects on Beaches in the Vicinity of the Sellafield Site"* J Brown and G Etherington HPA-CRCE-018 April 2011

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/340158/HPA-CRCE-018_for_website__2_.pdf

[158] "Radiation and Reason: the impact of science on a culture of fear"; Wade Allison, Wade Allison Publishing 2009 ISBN 978-0-9562756-0-8 (e-book);

[159] "Strange Glow: The Story of Radiation" T.J.Jorgensen. Princeton Univ Press 2016. ISBN 978-0-691-17834-9 Pers. comm. September 2019

[160] "Fallout: a journey through the nuclear age, from the atom bomb to radioactive waste" Fred Pearce. Portobello Books ISBN 978 1 84627 625 5 eISBN 978 1 84627 627 9

of Deception [161] "the shortcomings of the concept of dose … need no longer be an impediment to scientific accuracy … Microdosimetry allows for an accurate evaluation of the distribution of energy at this dimension of physical reality", before observing that radiation protection agencies persist in viewing doses as averages over entire organs.

This report has invoked the concept of scientific revolution. The changes in the handling of asbestos offer an analogous situation especially in view of the length of time that elapsed between the 1890s, when the first evidence of disease related to asbestos exposure was laid before Parliament, and 1972, when the causal link with mesothelioma was established beyond reasonable doubt. The impact on the asbestos industry has been severe but there are reasons to suppose that a shift in the perception of radiation risk will have a far more dramatic effect on the nuclear industry and its long-term liabilities.

[161] *A Primer in the Art of Deception*: Paul Zimmerman. Pub. Paul Zimmerman ISBN 978 0 615 23146 8 p.202

Appendix 1: Proposed agenda for a joint fact-finding approach: a document represented to the BEIS/NGO forum in January 2019 seeking collaborative discussion.

This document was discussed at the following Forum meeting in June 2019. BEIS said they could not participate in joint fact-finding as to do so would undermine COMARE. BEIS did offer to try to facilitate discussions between LLRC and "appropriate people".

Proposal to BEIS Nuclear NGO Forum for
Joint Fact Finding on a radiation risk dispute

Introduction

Disputes over radiation risk modelling have gone on since 1943 and much has been written about the science. This paper does not add to that literature; it is about process. It arises from the September 2018 meeting of the BEIS Nuclear NGO Forum in which Richard Bramhall of the Low Level Radiation Campaign (LLRC) argued for Joint Fact Finding (JFF) on issues arising from documented exchanges between LLRC and the BEIS Justification Application Centre (JAC) and subsequent recommendations from Welsh regulators Natural Resources Wales (NRW).

A meeting between Bramhall, Pete Wilkinson, and Umran Nazir with other BEIS officials briefly explored the background. It ended with RB and PW being asked for a proposal defining the scope and method of JFF. This paper is the outcome. BEIS asked for it to be available for discussion at the January 2019 Forum. Thirty minutes would be allocated at that meeting.

We begin by outlining the documents and their context. Since the documents from both LLRC and the JAC and its advisors address well-specified topics it has been possible to analyse their relevance and reliability. On that basis we feel there is a crisis of competence in bodies which have important policy roles but little accountability and no appetite for debate, even when Government Ministers have asked them to address specific issues.

At certain points the correspondence raises issues that are more to do with sociology than science. At the same time there are political, legal and regulatory implications which explain why this matter has come back to BEIS. The Joint Fact Finding is intended as a way of scoping and helping to resolve only the scientific differences of opinion. We leave aside the sociological, political, legal and regulatory aspects except for a section entitled *The frustrated search for consensus reporting*. We conclude with an outline of the structure of a JFF panel, its mode of working, and an agenda based on the correspondence between LLRC and JAC. COMARE's role cannot be overlooked but, for the sake of not over-complicating the paperwork, we do not propose to include their arguments (Footnote18) at this stage.

We recommend an initial read-through. The paper is intended to stand alone and to be comprehensible to a first-time reader. The web links to other documents are meant mostly to let readers check the account's veracity. The links are in footnotes.

LLRC's application for a Justification review

The present proposal arises from LLRC's application (November 2016) to the JAC for a review of the justification of the Hinkley Point C EPR.[1] EU Basic Safety Standards Directives allow for such a review if there is *new and important evidence*. A 2009 letter from the European Energy Commissioner [2] outlines the Justification principle and the European Commission's role in scrutinising the process.

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[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47936/666-decision-EPR-nuclear-reactor.pdf.

[2] http://www.llrc.org/llrc/regulation/subtopic/piebalgsletter030409.pdf

The evidence put forward by LLRC

LLRC's application, which was copied to COMARE at the same time, was based on two pieces of evidence:

1) an exchange in the journal *Genetics*. Bertrand Jordan, a CERN physicist, discussed the LifeSpan Studies (LSS) of Hiroshima and Nagasaki bomb survivors which are the basis of radiation risk estimates advised by the International Commission on Radiological Protection (ICRP). [3] He argued that public concerns about radiation are irrational because the LSS show that the highest dose survivors lose only one year of life despite having 42% more cancer than the low dose group, and their children appear to be unaffected. Chris Busby replied [4] that the LSS cannot be relied on because they have no information on internal radioactivity, because they ignore reports of acute radiation sickness in remote areas where there was Uranium fallout but where external doses were zero, and because the control population was abandoned when it turned out to be too healthy.[5] Dr. Jordan's response did not address these criticisms.[6]

2) a review of congenital malformations reported by official registries after Chernobyl.[7] The incidence rates observed are up to 59,000 times greater than ICRP would predict on the basis of the estimated doses. Since the LSS found no effect, ICRP assesses genetic risks using data from experiments in which large numbers of mice were exposed to X-rays.[8]

Significance for regulation

Both pieces of evidence refer to recent changes in the understanding of the biological effects of radiation, especially for internal exposures to nanoparticles and elements such as Uranium that have chemical affinity for DNA. This defines a conceptual error in radiation risk assessments that employ the ICRP's *absorbed dose* quantities.[9] A large number of studies show health effects that cannot be explained since the doses as modelled by ICRP appear too low, leading to calls for re-evaluation.[10] There are far-reaching implications for regulatory standards based on radiation dose quantities and the concept of *tolerable risk* [11] as applied by environment agencies and others who in the last two years have declined to address the science of risk modelling, leaving PHE and COMARE as the only interlocutors.[12]

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[3] http://www.genetics.org/content/203/4/1505
[4] http://www.genetics.org/content/204/4/1627
[5] Moriyama, I. M., and H. Kato, 1973 Mortality experience of A-bomb survivors 1970–72, 1950–72. JNIH-ABCC Life Span Study Report 7 (Technical Report 15–73); pp 6–7. Hiroshima Japan: ABCC (quoted in ref 4).
[6] http://www.genetics.org/content/204/4/1631
[7] Schmitz-Feuerhake, Busby C, Pflugbeil P *Genetic Radiation Risks-A Neglected Topic in the Low Dose Debate*. Environmental Health and Toxicology. 2016. http://dx.doi.org/10.5620/eht.e2016001.
[8] *Detriment adjusted nominal risk coefficient for heritable effects:* ICRP103 Table A.4.4.
[9] e.g. *There are important concerns with respect to the heterogeneity of dose delivery within tissues and*
cells from short-range charged particle emissions, the extent to which current models adequately represent such interactions with biological targets, and the specification of target cells at risk. Indeed, the actual concepts of absorbed dose become questionable, and sometimes meaningless, when considering interactions at the cellular and molecular levels.
Report of Committee Examining Radiation Risks of Internal Emitters; Chapter 2 *Risks from Internal Emitters Part 2* para.11
(https://webarchive.nationalarchives.gov.uk/20140108135436/http://www.cerrie.org/)
[10] e.g. European Committee on Radiation Risk Recommendations 2010
http://euradcom.eu/ecrrrecommendations-2010/
[11] see http://www.hse.gov.uk/risk/theory/r2p2.htm
[12] e.g. http://www.llrc.org/campaigns/justification/RResponsetoPWilkinson-final170717.pdf

LLRC's dialogue with JAC and COMARE

There were two rounds of correspondence with the JAC:-
the application [13]
a response letter [14] which was based on and incorporated an advice note from Public Health England [15]
a response from LLRC [16]
a second response from the JAC [17] indicating that any further correspondence would be treated as vexatious and would not be considered.
COMARE also replied to LLRC [18] and made a brief verbal comment at the BEIS/ Nuclear NGO meeting in Church House, Westminster on 12th September 2017.
LLRC's position is that the responses from the JAC, PHE, and COMARE are, in various ways, irrelevant, evasive and misleading.

The Cardiff mud dump and LLRC's correspondence with Natural Resources Wales

In December 2017 LLRC was asked to advise Welsh campaign groups on a licence issued by Natural Resources Wales (NRW) that allows 300,000 tonnes of radioactively contaminated sediment from the seabed off the Hinkley Point C site to be dumped in the Severn Estuary close to Cardiff.[19] The licence is based on tests conducted by the Government laboratory CEFAS. LLRC advised that although the CEFAS testing could not reveal directly whether the mud contained Uranium and Plutonium there was indirect evidence that these elements were present. Moreover, data from UNSCEAR [20] and RIFE [21] showed they were likely to be present in the form of relatively insoluble particles that, once dumped into a circulatory system of high tidal energy, would be resuspended by well-known mechanisms. This would make them available for inhalation and ingestion so the dumping was likely to cause the same kind of exposure as the Chernobyl accident, above-ground nuclear weapons tests, and the Hiroshima and Nagasaki bombs. The correspondence between LLRC, the JAC, COMARE and PHE was therefore germane and LLRC wrote twice [22],[23] to Diane McCrea the Chair of NRW arguing, on the basis of detailed analysis, that NRW was relying on inadequate radiological opinion. A reply from NRW [24] insisted that NRW was required to follow procedures developed by the International Atomic Energy Agency (IAEA) and that CEFAS had analysed the samples in accordance with these internationally recognised standards. Ms McCrea failed to address the submitted evidence on radiological risk, recommending only that LLRC should *continue to communicate with BEIS its advisory bodies*.

LLRC replied on 13th July [25] asking why NRW failed to require a more precautionary assessment than IAEA's; Dr. Tim Deere-Jones had briefed the Senedd Petitions Committee, 12 March 2018, that there is no legal restriction on the Welsh Government and NRW *taking or recommending independent action to require more than the normal protocols*. He had received no answer. LLRC now asked NRW to consider even more specifically whether the evidence provided was robust enough to trigger precautionary

[13] http://www.llrc.org/campaigns/justification/JustificationBusbyBramNov2016.pdf
[14] http://www.llrc.org/campaigns/justification/Richard Bramhall - 2017 - 03.pdf
[15] http://www.llrc.org/campaigns/justification/PHE Analysis of Justification Request EPR.pdf
[16] http://www.llrc.org/campaigns/justification/LLRCtoJAC22052017.pdf
[17] http://www.llrc.org/campaigns/justification/Richard Bramhall - 2017 - 07.pdf
[18] http://www.llrc.org/campaigns/justification/COMAREbusby2017com.pdf
[19] http://www.valeofglamorgan.gov.uk/Documents/_Committee Reports/Cabinet/2017/17-10-09/Appendices/Disposal-of-Dredged-Material-Associated-with-the-Construction-of-Hinkley-Point-CPower-Station-Appendix-2.pdf Now deleted from Vale of Glamorgan site (July 2019).
[20] http://www.unscear.org/docs/publications/2000/UNSCEAR_2000_Annex-C-CORR.pdf Table 34
[21] RIFE 1 (1995) p.30, RIFE 22 (2016) p. 123: AEMR Number 23 (*Radioactivity in Surface and Coastal Waters of the British Isles 1989*: page 43.)
[22] http://llrc.org/campaigns/muddump/June2018docs/RB2NRW050618.pdf
[23] http://llrc.org/campaigns/muddump/June2018docs/RB2NRW210618.pdf
[24] http://www.llrc.org/campaigns/muddump/June2018docs/NRWtoLLRC09072018.pdf
[25] http://llrc.org/campaigns/muddump/June2018docs/LLRCtoNRW13072018IAEA.pdf

provisions of the Environment (Wales) Act 2016 [26] and whether the Welsh Government and NRW might consequently be breaking Welsh law. Ms. McCrea resigned six days later for unrelated reasons.

LLRC's approach to the Welsh Environment Secretary

LLRC then sent the same material to the Welsh Environment Secretary, Lesley Griffiths AM who replied [27] that

all the tests and assessments carried out by NRW and their experts in this specific field concluded the material is within safe limits and poses no radiological risk to human health or the environment.

Concerning the evidence on radiation risk she referred LLRC back to NRW as the licensing authority.

A further approach to NRW

On 18 August 2018 LLRC emailed Dr. Madeleine Havard,[28] NRW's Acting Chair, asking how, in general, NRW assesses whether new information raises *uncertainties* in the terms of the Environment (Wales) Act 2016 and what NRW did to evaluate whether any uncertainty was raised by the two letters to Diane McCrea in June ([22, 23]). Dr Havard's reply [29] gave no answer to the question of how NRW assesses whether new information raises uncertainties; on the question of what NRW did to evaluate LLRC's analysis of the Justification correspondence Dr. Havard relied on the irrelevant assertion that NRW were *satisfied that Cefas analysed the samples in accordance with* [IAEA's] *internationally recognised standards*. She repeated the advice to take the scientific issues back to BEIS.

A joint approach to the Welsh Environment Secretary

On 4th September 2018 Bramhall wrote to Education Secretary Kirsty Williams AM [30] on behalf of LLRC and Cllr. Ernie Galsworthy, co-Chair of the Nuclear-Free Local Authorities' Wales Forum. He asked her to arrange a meeting with Environment Secretary Lesley Griffiths to discuss Joint Fact Finding on the scientific issues raised by the correspondence with the JAC. Noting that NRW has insisted the science be taken back to BEIS he wrote that there was no objection to BEIS contributing to JFF but that the peculiarly Welsh angle represented by the Cardiff mud dump and the large amount of public concern should lead Assembly Members to feel a sense of ownership. The message was passed on [31] but elicited only a brush-off from Ms. Griffiths' Assistant Diary Secretary. [32]

In a Senedd Plenary debate in May [33] Ms. Griffiths had dismissed concerns about the mud, saying *There is no scientific basis for any further testing or assessments to be done, so I think if they did that, that would set out a very dangerous precedent.* In an October Plenary she went further, [34] speaking of campaigners' *misinformation, scaremongering, lies, myths* and *untruths*, and she has committed considerable public expenditure by giving NRW a formal Direction that requires them *to reassure the*

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[26] specifically Part 1 Introduction Para. 4 which require NRW to adhere to principles of sustainable management of natural resources, viz.
(a) to manage adaptively, by … where appropriate, changing action;
(b) to consider the appropriate spatial scale for action;
(c) to promote and engage in collaboration and co-operation;
(d) to make appropriate arrangements for public participation in decisionmaking;
(e) to take account of all relevant evidence and gather evidence in respectof uncertainties;
(f) to take account of the benefits and intrinsic value of natural resourcesand ecosystems;
(g) take account of the short, medium and long term consequences ofactions;
[27] http://llrc.org/campaigns/muddump/JFFdocs/LG0153218_Outgoing_0.pdf
[28] http://llrc.org/campaigns/muddump/June2018docs/RichardBramhallEmailToNRWAug182018.pdf
[29] http://llrc.org/campaigns/muddump/June2018docs/NRWdutyofcaretoRichardBramhallAugust2018.pdf
[30] http://llrc.org/campaigns/muddump/JFFdocs/KirstyWilliamsJFFproposal04092018.pdf
[31] http://llrc.org/campaigns/muddump/JFFdocs/JFFrequesttoEnvtSecviaKirstyWilliams04Sept2018.pdf
[32] http://llrc.org/campaigns/muddump/JFFdocs/ThankyouforyourinvitationEnvSecdeclinesJFF.pdf
[33] http://record.assembly.wales/Plenary/4986 - A43752 (= transcript; see para. 424 at 17:27 hrs)
[34] http://record.assembly.wales/Plenary/5356?lang=en-GB - A45903 (para 471)

public. We therefore seem to have reached a complete breakdown of communication with no prospect of rational dialogue with the authorities in Wales.

BEIS Forum discussions and the meaning of *consensus*

NGO concern about the possible underestimation of radiation risks has been a consistent theme in the Forum. In 2011 the NGOs identified [35] a number of topics to inform discussion with COMARE in 2012.[36] On 28th February 2013 [37] Bramhall told the Forum that most of those topics had not been discussed. He was asked to propose a way forward. The NGOs adopted resolutions requesting JFF and discussions about the process went on for two years. The most informative minutes on the topic [38] are missing from the Government archive but they show the Department willing to get on with JFF although they doubted that consensus *could be reached given two decades of discussions and formal processes which have not achieved* [it]. Rather than argue about what has and hasn't been achieved we feel it's more constructive to ask what consensus would look like. Experience shows that the report is the key element.

The frustrated search for consensus reporting

In 2001 Michael Meacher set up CERRIE with an oppositional structure. At that time he, like many other politicians and civil servants, was acutely aware of the embarrassment of finding that BSE could cross species barriers despite the consensus opinion of the Spongiform Encephalopathy Advisory Committee. To inform his position on radioactivity he wanted a more challenging kind of committee. The remit he set was

The committee […] aims to reach consensus where possible. On topics where differences of view remain after its deliberations, it will explain the reasons for these and recommend research to try to resolve them. […] CERRIE will produce a report that is agreed by all its members. The report will not be subject to amendment […][39]

In 2004 he wrote:

Unfortunately, it seems that the procedures which prevailed in the Committee, while they have allowed discussion of a wide range of topics, have produced a Final Report which does not accommodate a full and fair representation of all views. More seriously, from the point of view of taking this debate forward, the Report fails to explain the reasons for the continuing disagreements. This applies, in some cases, to what look like quite basic issues.[40]

Bramhall briefed the Forum in 2014 on CERRIE, Safegrounds and STOA as examples of biased reporting. [41] Subsequently he found that archived documents of Safegrounds had been airbrushed even more

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[35] Andy Blowers' *Key Issues and Controversies concerning the effects of radiation on health*, compiled to inform the 2012 meeting of the NGO Forum and COMARE. Not found on the archive:— http://webarchive.nationalarchives.gov.uk/20121217153819/http://www.decc.gov.uk/en/content/cms/meeting_energy/nuclear/forums/non_gov_org/non_gov_org.aspx

[36] Found here https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/fi66718/7033-minutes-decc-ngo-forum-panel-disc-comare.pdf but during drafting the present report early in 2019 not in October.

[37] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/200217/minutes_decc_ngo_forum_meeting_28_feb_2013.pdf

[38] i.e. minutes of 10th Forum meeting 1st October 2013. Missing from https://www.gov.uk/government/groups/non-governmental-organisation-forum as at 28 Oct. '19

[39] Rt. Hon. Michael Meacher, Minister of State for the Environment, at DEFRA announcing formation of the Committee Examining Radiation Risk from Internal Emitters (CERRIE) July 2001.

[40] Ex-Environment Minister Michael Meacher Foreword to Minority Report of Committee Examining Radiation Risks of Internal Emitters (CERRIE) 2004 ISBN: 0-9543081-1-5 p.1

[41] see page 3 of http://llrc.org/campaigns/muddump/JFFdocs/JFFradhealth2014proposal.pdf

extensively and more tendentiously than he'd realised. We can now add a further example from the Forum itself — Baroness Verma's suggestion [42] in 2015 that NGOs might be involved in a review or *Restatement* by Oxford University to be published in Proceedings of the Royal Society. In the event there was no NGO involvement and the *Restatement* as published [43] endorsed the ICRP position omitting any mention of the evidence in LLRC's application to the JAC although it had been published in the literature more than a year earlier. The *Introduction* reported that risks are *widely debated* and that *some people believe the dose limits are too strict and impose unreasonable costs on the use of radiation, while others believe that they are not strict enough and allow too much risk*. The review cited a paper arguing for less stringent regulation and a paper refuting that idea. It cited no evidence in support of the idea that risks might have been underestimated.

Richard Bramhall has also questioned the accuracy of the minutes of the Forum meeting with COMARE in September 2017. He has raised doubts about the claim that COMARE addressed the evidence of congenital malformations after Chernobyl (Fn7), as Energy Minister Richard Harrington had asked them to do.[44] This is unresolved at the date of writing.

Consensus reporting defined:— *a report agreed by all its members*

We close this matter by recommending that Meacher's formula — *a report that is agreed by all its members* — adequately defines consensus. There is one caveat:— achieving the goal of a single report which captures disagreements will require differing views of any particular topic to go through as many iterations of the draft report as it takes for each side to address the other's arguments and to agree, finally, that the reasoning is clear.

A structure for Joint Fact Finding.

We propose a panel composed of three NGO representatives from the Forum and three BEIS appointees, possibly departmental Scientific Advisers. We propose to appoint NGO representatives who display a co-operative frame of mind, a willingness to grapple with complexity, and an ability to write simply and clearly. NGO representatives will not necessarily be scientifically versed in radiological matters although they will possess a working knowledge of the issues. BEIS could appoint as panellists the scientists they wish to rely on for scientific input to the process. This panel of six people will be required to work closely together throughout the process to ensure a smooth progression of the exercise which will consist primarily of assessing written answers to the questions set out above – after suitable refinement should it be required - asked of a number of experts identified through a collaborative process entered into by the panel members. Although face-to-face meetings with experts will probably be necessary on occasions, a predominantly remote-working approach will reduce the number of 'in-person' meetings required to a minimum, limiting the costs of undertaking the exercise, reduce the need to travel and will ensure more effective use of time.

The secretariat should be external and professional, in the manner of Ciria providing the secretariat for Safegrounds. The nature of the record of meetings will be agreed by the panel members with the objective of ensuring clarity and unambiguity.

It is likely that the panel will be required to meet face-to-face at least once before the process begins in order to agree structural and administration matters. This will include the manner in which the experts are identified and recruited, minuting and progressing the panel sessions, be they remotely conducted or face-to-face, remuneration issues, follow-up, dispute resolution and report writing. As in all matters associated with a joint fact-finding exercise, it is essential to conduct proceedings in a collaborative and co-operative manner: all aspects of the exercise as well as the final report and the process through which it is arrived at must be agreed by all members of the panel.

Proposed agenda for Joint Fact Finding.

With reference to LLRC's first letter to NRW (footnote 22) and the studies cited therein and in the correspondence between LLRC and the JAC:

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[42] http://llrc.org/campaigns/muddump/JFFdocs/BaronessVermatoBramhallandWilkinson.pdf

[43] *A restatement of the natural science evidence base concerning the health effects of lowlevel ionising radiation* https://dx.doi.org/10.6084/m9.figshare.c.3838153 7 September 2017

[44] http://llrc.org/campaigns/muddump/June2018docs/App10EnergyMinistertoRB.pdf

1. Do the Life Span Studies (LSS) of Hiroshima and Nagasaki survivors lack unexposed control populations and /or information on internal radioactivity? If so, what are the implications for radiation protection standards? (pp. 2, 3)

2. Do the studies of nuclear industry workers lack unexposed control populations and /or information on internal radioactivity? If so, what are the implications for radiation protection standards? (p.3)

3. Is an average absorbed dose model appropriate for assessing risks from exposure to internal particulates? Can any discrepancies be quantified? (pp. 3, 4)

4. Does fragmentation of radioactive particulates on beaches lead to increased hazard following inhalation, ingestion or absorption? (pp. 4, 5)

With reference to LLRC's second letter to NRW (footnote 23) and the studies cited therein and in the correspondence between LLRC and the JAC:

5. In respect of references 16, 17, 18 in the letter (footnote 23), is there epidemiological evidence from weapons test fallout and Chernobyl to support the hypothesis that internal particulates are more hazardous than predicted by ICRP? If so, can the discrepancy be explained and quantified

6. What are the implications for radiation protection of comments from BEIS and Professor John Harrison concerning individual dose estimates in ecological studies? ((footnote 23) p. 6 line No. (*Fourth* etc). ... and p.7)

7. With reference to Public Health England advice to BEIS (Footnote 15 of this document) and LLRC's response (Fn 16) [Note that page and line references in the PHE advice refer to the LLRC application to JAC - Fn 13 of this document]

7.1 Did PHE use a circular argument about the linear dose response assumption? (Fn 15 p.1, numbered item 1, 2nd para) and LLRC's response (Fn 16 p.2 lines 1-24)

7.2 Did PHE misdirect BEIS on internal contamination and Uranium? (PHE's p.2 Section 2(b) and LLRC's answer Fn 16 p.4 last paragraph *PHE misdirection on LSS, internal contamination and Uranium.*

7.3 Did PHE misdirect BEIS on the significance of rainfall and acute radiation syndrome in areas remote from Hiroshima and Nagasaki? (PHE's p.2 Section 2(c) lines 7-17 and LLRC's answer Fn 16 p.5 lines 3-25 ending *fallout caused acute health effects in people who got no external irradiation.*

7.4 Did PHE misdirect BEIS on the interaction between natural gamma radiation and Uranium in body tissue? (Fn 15 2.(c) lines 1-7 and LLRC's answer Fn 16 p. 5 *Uranium: the Photoelectric Effect and Uranium binding to DNA as far as p.6 line 19*

7.5 Did PHE make an adequate argument for dropping the control group in the Life Span Study of Japanese A-bomb survivors when it turned out to be too healthy? (Fn 15 2.(a) *selection of control groups* and LLRC's answer Fn 16 p.6 *Dropping the controls* as far as p.7 line 5)

7.6 What is the significance of differing conclusions in studies of the ratios of male to female babies born to Japanese A-bomb survivors? (LLRC's letter 16 p.7 line 14-22 and JAC's answer Fn 17 p.2 *Ratios of male to female births:* line 32 etc.)

7.7 Did PHE provide any relevant response to the reported increases of congenital malformation in babies born after the Chernobyl accident (ref 13 p.2 para.2 *Evidence of genetic damage leading to heritable effects in those exposed to Chernobyl fallout in Europe*)?

Richard Bramhall, LLRC
Peter Wilkinson TASC
Supported and endorsed by NFLA

7th January 2019

The perceived errors in the ICRP and similar models led in 1998 to the formation in Brussels of the European Committee on Radiation Risk (ECRR, in French CERI). At that time, cancer results from the Chernobyl affected territories of the former USSR were showing persuasive evidence that the predictions of the ICRP model were wildly incorrect. The ECRR, a loose association of about 40 scientists, doctors, epidemiologists and other experts began developing a separate risk model. This was completed and published in 2003. The core group consisted of Dr. Chris Busby, Prof. Alexey Yablokov, Prof. Inge Schmitz-Feuerhake, Dr. Rosalie Bertell, Dr. Molly Scott Cato and Prof. Alice Stewart. Later they were joined by Dr. Sebastian Pflugbeil and Prof. Elena Burlakova, Prof. Yuri Bandashevsky, Prof. Rose Goncharova and others. In 2009 they published the Lesvos Declaration[45] which called for the urgent abandonment of the ICRP model.

The ECRR Model was published in 2003[46] and translated and reprinted in French, Russian,[47] Spanish and Japanese. It was modified and re-published in 2010[48] and is currently being modified and added to for publication in 2019. Meanwhile Dr. Bertell and Professors Burlakova, Stewart and Yablokov have died.

The ECRR model is based firstly on the facts that:

- the basis of the ICRP model in the Japanese A-Bomb LSS is unsafe for a number of reasons, principally because **(a)** the unexposed control group were discarded in 1973; use of a true control group by the Wanatabe et al study show significant cancer excess in the low dose group **(b)** all members of all study groups were exposed to internal Uranium particles from the Black Rain and if internal exposures carry greater risk dose for dose this falsifies all the results and **(c)** all groups were assembled 7 years after the bomb and were therefore a survivor population that does not represent a normal population:
- since the target for radiation is the nuclear DNA on the chromosomes, averaging energy density over large masses of tissue is an insecure method for evaluating risk from internal radioisotopes that have **(a)** affinity for DNA **(b)** decay sequences that can damage the cell inside its repair replication period of 12h **(c)** considerations of photoelectron emission by high atomic number elements exposed to natural background radiation or to medical X-rays;
- that ICRP overlooks the particular issue of inhaled sub-micron radioactive particles. There is persuasive and mechanistic evidence that such exposures are the cause of high levels of birth defects and child cancers in areas where such exposures are endemic. One example is the Seascale leukemia cluster near Sellafield;
- the dose response over the range of doses relevant to radioactive pollution of the environment is not linear but biphasic, owing to **(a)** up-regulation of repair systems at low doses which can be overwhelmed (Burlakova) and/ or **(b)** presence of two populations of cells with different radiation sensitivities (Busby).

These problems can be dealt with by a model that treats radiation risk in the low dose region separately from the high dose region and which employs the same methodology as ICRP to invoke biological weighting factors for different isotopes based on their affinity for DNA. A separate weighting factor is developed for physical dosimetric regimes; this in principle is the same as using the Quality Factor of the ICRP to convert Grays to Sieverts (the multiplier of 20 for alpha dose). The development of the weighting factors for different internal exposures was carried out using biochemical evidence and epidemiological evidence from populations exposed to internal radioactivity. Application of the model to results from Chernobyl populations in the former Soviet countries and Sweden shows good agreement with model predictions.

Some aspects of the ECRR model are briefly discussed below.

[45] https://euradcom.eu/lesvos-declaration/
[46] ISBN 1-897761-24-4
[47] ISBN 5-87317-187-4
[48] ISBN 978-1-897761-16-8

1. The linear no threshold fallacy
ECRR argues that it is clearly impossible for the dose response to be linear over the whole range since some cells/ individuals will die at higher ICRP doses. Examination of all the data, especially the nuclear worker data, shows clearly that there is a high risk per dose at low doses and this falls to almost zero at intermediate doses with an increase at high doses, then a fall off again (as people die). Deaths of individuals from radiation exposure will include confounding causes (coronary disease, strokes) and so this will also contribute. Studies of birth defects and leukemia after Chernobyl provide unequivocal evidence of the biphasic dose response. These studies provide evidence of a 10,000-fold error in the current ICRP risk for genetic effects which are obtained from studies of externally irradiated rodents.

2. Chemical affinity for DNA

DNA is the target for radiation genetic effects (genotoxicity) which lead to cancer and to birth defects. The DNA molecule has a phosphate polymer backbone, the charges stabilised by Calcium Ca++ and Magnesium++ ions. Group 2 ions like Barium and Radium therefore bind to the backbone as does Uranyl ion UO2++. Therefore radionuclides Ca45, Ba90, Ra226, Ra224 and UO2 have high affinity for chromosomal DNA and focus the alpha and beta radiation into the target. Recoil ionisation, transmutation ionisation will also provide effects which are not included in any ICRP assessment of risk.

3. Photoelectric effect and high atomic number elements: Uranium
The ECRR scientists identified an important radiobiological mechanism in 2005 concerning ionisation enhancement close to internal atoms and micro-particles of high atomic number Z elements like Uranium and Thorium, but also non -radioactive elements of high Z like Platinum, Gold, Lead, Bismuth etc. Since absorption of X-rays and Gamma rays is proportional to the fourth power of the atomic number, high Z elements preferentially absorb natural background radiation. They then re-emit the absorbed energy as photoelectrons, which are identical to high energy beta particles; these local radiations will cause tissue damage in the same way as beta particles. If the high Z element has affinity for DNA this represents a serious radiogenotoxic mechanism which is overlooked by the current risk models. The effect is incorporated into a new set of risk multipliers which will be published in 2019. For Uranium particulates and their local high Uranyl ion concentrations, the effect is believed to be responsible for high levels of childhood and adult cancer near contaminated sites like Sellafield. The overall weighting for Uranium will be between 1000 and 10000 depending on specific exposure types.

4. Alpha emitting particles

Hot particles have been an area of concern since the 1980s when Gofman and Tamplin raised the issue of high ionisation density near the particles. The ECRR weights alpha emitting "hot" particles with a factor that depends on the particle diameter and its activity. Here the high activity particles (plutonium, americium) carry lower weightings than the low activity particles (uranium, thorium) since the biphasic dose response is employed to allow for cell killing at high local doses. Specific values will be published in the 2019 report.

5. Sea to land transfer of alpha emitting particles.
The ECRR identifies the dosimetric vector involving inhalation of micron sized alpha-emitting particles of Uranium, Plutonium, Americium, Neptunium and other nuclides as the principal cause of increased rates of cancer and leukemia in adults and children living both near nuclear sites which emit these from stacks and to the sea or tidal rivers and near the contaminated shores of the sea, especially the Irish Sea. Such radioactive particles of below 10 microns have been detected in intertidal sediments and in the engine air filters of vehicles driven near the contaminated coasts. They provide high local doses to respiratory tissues and to digestive tissues driving up rates of cancer, and most are small enough to transfer to the lymphatic system and therefore irradiate tissues in many parts of the organism.

6. Explanation of childhood cancer and radiation near nuclear sites.
The ECRR has an explanation for the increased rates of child leukemia and other cancer near nuclear sites. This will be presented in ECRR2019. Briefly, the ICRP and its defenders base their position that the childhood cancer found near nuclear sites cannot be due to radiation because there

was no dose proportional increase over the peak period of weapons tests in 1959-1963 when exposures were higher than they could be at nuclear sites. The ECRR point out that the main studies which appeared to show there was no association between internal dose and child leukemia from 1959-70, for example the Nordic leukemia study of Darby et al 1993, were **(a)** dishonest in that they employed moving averages but placed the data point at the wrong year and **(b)** had no correct data before 1959. The explanation for the failure to see an increase over the peak period is that in the same period there was a peak in infant mortality due to foetal death from the internal exposures. The ECRR points out that it is now well accepted that childhood leukemia is a congenital or teratogenic consequence of exposure in utero and/or of pre-implantation and sperm genetic effects. Therefore, the dose response must be biphasic. Therefore, at the high doses experienced in the fallout period, the child leukemia rate was confounded by foetal death seen as the peak in infant mortality in the studies. In fact, studies of infant leukemia after Chernobyl in 5 countries show exactly this biphasic effect. ECRR points out that since the delay between exposure and clinical expression of leukemia and cancer is a function of dose, the effect of increasing exposures move in the sequence:

High dose: No child leukemia—foetus dies. Birth rate falls (Hiroshima)
Next lower dose: No child leukemia—foetus dies. Infant mortality increases (fallout)
Next lower dose: infant leukemia increases with a biphasic dose response where dose are known
Next lower dose: Childhood leukemia 0-4
Next lower dose: Childhood leukemia 5-9
Next lower dose: Childhood leukemia 10-14

7. ECRR risk model and quality factors

There is insufficient room to explain the calculation of radiochemical genotoxicity doses here. The ECRR adjusted dose is the Muller or Mu and its method of calculation is given in ECRR2010 together with a table of the weighting factors employed. A new table of weighting factors including assessments of risk from the Secondary Photoelectron effect will be published in 2019.

Christopher Busby
Scientific Secretary, ECRR

28th September 2019

Appendix 3

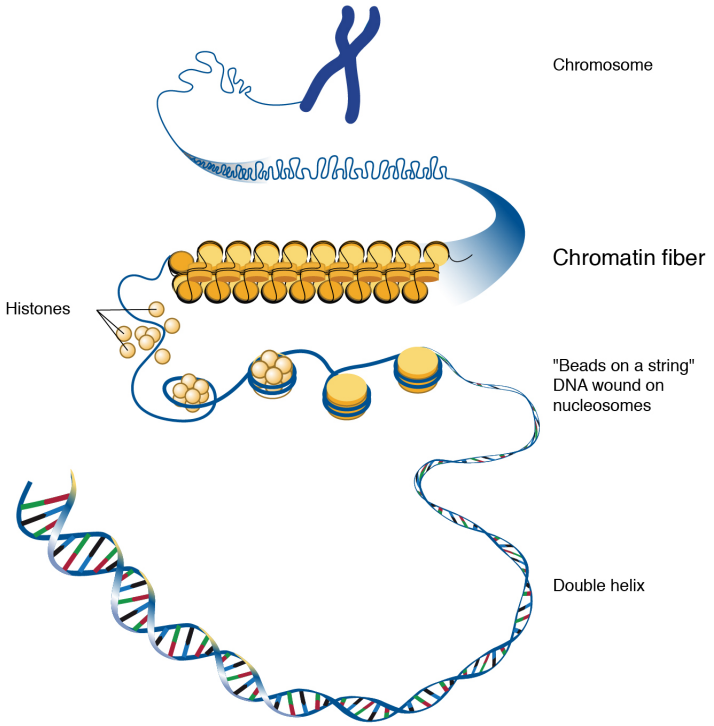

Illustration: how the DNA molecule is packed into chromosomes

Appendix 4: Bone Cancer

Bone cancer, strontium 90 and nuclear weapons testing

Bone cancer is a rare disease. Authorative documentation on its causes is equally scarce but one source of information which offers a plausible instigator and contributory factor for the disease is the 1995 publication by Chris Busby, Wings of Death – Nuclear Pollution and Human Health[150] *which documents Busby's ground-breaking work to establish a link between the high incidence of bone cancer in Wales and the comparatively high level of strontium 90-bearing precipitation in that country.*

The following is a summary of Busby's document:

The radionuclide most associated with bone cancer is Strontium 90 (Sr-90)[151] which is known to bio-accumulate in the bones. Sr-90 decays to Yttrium-90, which then decays further. This second decay event has a high probability of occurring while the cell is repairing damage caused by the first. The second event defeats the cell repair mechanism because the mechanism itself is irreversible and has no means of repairing damage inflicted after it begins. Bone cancer rates have been increasing, particularly in Wales, since the early 70s.

!958 to 1962 saw the peak in fallout from atmospheric nuclear weapons testing washed down by precipitation. Looking in areas of high rainfall in Wales on the basis that there would be found the highest levels of Sr-90, Busby found a 350% increase in bone cancer, relative to the average incidence of the disease for England and Wales combined. This represented a 500-fold error in the existing estimate of radiation-induced bone cancer hazard.

On publication of Busby's findings in 1992, the Wales Cancer Registry at first denied the accuracy of the figures, claiming there was 'no case to answer'. Two years later, in 1994, writing in the British Medical Journal, the then Director of the Wales Cancer Registry (WCR), Dr. Mary Cotter, stated that the bone cancer data held by the WCR were insecure and were being validated. In November 1994, the latest, validated data were published and confirmed the correlation between Sr-90 fallout and bone cancer incidence. This correlation was further reinforced by the appearance in the published statistics for bone cancer incidence in Wales of a significant peak in cases recorded in 1979. Busby mapped this peak to the 1959 corresponding peak in Sr-90 fallout, lagged by 20 years so that a comparison between cause and effect trends can be seen more easily.

The use of what Busby calls the 'fallout spectrum with time' to detect elevated cancer rates lagged by 20 years leads to the inevitable conclusion that 'nearly all the Welsh cancer increases' appear some twenty years after significant historical events: the Test Ban Treaty which led to reduced fallout between 1959 and 1961, following the testing of comparatively small yield bombs between 1954 and 1958 and the resumption of testing of very high-yield bombs in 1962 which caused another exposure peak of the global population in 1963. This nuclear weapons' testing history or 'fingerprint', as Busby calls it, foreshadows the peaks in Welsh bone cancer incidences by 20 years. Busby argues that the 'correlation coefficient' between cause and effect trends (i.e. Sr-90 atmospheric deposition from testing and cancer incidences in Wales) is significant, approaching the 99.5% level. He concludes that, '…it is extremely likely … that the bone cancer is cause (*sic*) by or at least related to the Sr-90 exposure.'

Cancer of the bone and articular cartilage is osteogenic sarcoma or osteosarcoma, a rare disease yet the fourth most common in people under the age of 25. Studies indicate that ionising radiation is the only environmental exposure which is consistently associated with it but there is a wide discrepancy between the number of bone cancers observed and the number predicted by the risk assessments used by health and regulatory authorities. Between 1979 and 1988, the rate of excess bone cancers in Wales compared to those identified in England over the same period was 17.4 per 100,000 people. This represents 493 excess cancers in the 2.9 million Welsh population over that decade. The increases in Welsh cancers

reflect the ‘immediate annual dose’ and is evidenced most starkly in the increases in bone cancer. These increases are not predicted or accommodated by current risk assessment. Using the rate of bone cancers per 100,000 English people of an average of one a year gives an expected annual number of 30 cases in a Welsh population of 2.9 million. Between 1984 and 1989, the actual number of cases was an average of 70 cases a year, more than twice the number predicted.

Appendix 5 Glossary and selected abbreviations

ABSORBED DOSE The quantity of energy imparted by ionising radiation to a unit mass of matter such as tissue. Absorbed dose has the units J kg–1 and the specific name gray (Gy), where 1 Gy = 1 joule per kg.

ADDITIVITY (of countable entities) The extent to which something is additive, which means " characterised by, being, or producing effects (such as drug responses or gene products) that when the causative factors act together are the sum of their individual effects" (Merriam-Webster).

AETIOLOGY The study of causes of disease.

ALL See LEUKAEMIA. AML See LEUKAEMIA.

ATMOSPHERIC PRESSURE Force per unit area exerted by the air above the surface of the Earth. Standard sea-level pressure, by definition, equals one atmosphere (atm), but pressure varies with elevation and temperature.

BACKGROUND RADIATION Radiation that comes from naturally occurring radioactive material in the ground and from cosmic rays irradiating the Earth from outer space. The UK average dose from background radiation is 2.2 millisievert (mSv) per year: regional averages range from 1.5–7.5 mSv per year.

BECQUEREL (Bq) A unit of radiation equal to one disintegration per second. Discharges are normally expressed in: Megabecquerels (MBq) – one million Bq Gigabecquerels (GBq) – one thousand million Bq Terabecquerels (TBq) – one million million Bq

CARCINOMA A malignant tumour that may spread to surrounding tissue and distant areas of the body.

BIPHASIC in epidemiological studies, the appearance of a dose response curve that does not conform to any expectation that dose has a consistent relationship with effect but shows an increase at low dose followed by a falloff at higher dose and a further increase at still higher dose.

BLACK BOX In science, computing, and engineering, a black box is a device, system or object which can be viewed in terms of its inputs and outputs (or transfer characteristics) without any knowledge of its internal workings.

BONE SEEKERS Elements which are chemically similar to calcium so that they tend to be deposited in bone.

CASE–CONTROL STUDY A study in which the risk factors for a group of individuals identified as having the disease, the *cases*, are compared to those for a group of individuals not having the disease, the *controls*.

CENSUS The enumeration of an entire population, usually with details being recorded on residence, age, sex, occupation, ethnic group, marital status, birth history, and relationship to head of household.

CLL See LEUKAEMIA. CLUSTERING The irregular grouping of cases of disease in time (where cases of a particular disease which might normally occur at a fairly constant rate in a community appear with unduly high frequency in a certain time period); space (where cases of a particular disease occurring within a certain time period tend to cluster in a well-defined location); or in both time and space (where cases that occurred close together in space would tend also to be close in time, eg in the aetiology of some rare diseases such as leukaemia).

COHORT/STUDY A study design used in analytical epidemiology. Cohort studies are designed to answer the question, 'What are the effects of a particular exposure?' They compare a group of individuals with the exposure under consideration to a group without the exposure,

or with a different level of exposure, or to the country as a whole. The groups (cohorts) are followed over a period of time, and the disease occurrence is compared between the groups or between the cohort and rates expected from national statistics.

COLLECTIVE DOSE Collective dose is a measure of the total amount of effective dose multiplied by the size of the exposed population. Collective dose is usually measured in units of person-sievert or man-sievert.

CONFIDENCE INTERVAL (CI) An interval calculated from the data to indicate the (im)precision of an estimate of some parameter, eg the risk of a disease. A CI conveys the effect of sampling variation on the precision of the estimate. Specifically, the true rate will lie inside a 95% CI on 95% of occasions. This 'confidence coefficient' is often chosen to be 95%, although this is entirely arbitrary.

CONFIDENCE LIMIT (CL) A quantity calculated from the data to indicate a limit below (or above) which a parameter is unlikely to lie, in the sense that in a stated proportion of such calculations (say 97.5%), the calculated limit will be less (or greater) than the true value. Two such limits form a (95%) confidence interval.

CONFOUNDING FACTOR Confounding is a problem in epidemiological studies which arises when there is a factor associated with both the exposure being investigated and the disease under study. This can give rise to an apparent relationship between the factor being investigated and the disease, even though the factor did not cause the disease. For example, suppose lung cancer was being studied in workers exposed to a particular chemical. If those exposed to higher levels of the chemical smoked more than other workers, then the chemical would be associated with lung cancer even if it did not actually cause the disease. The problem can be addressed in the design and analysis of studies but requires that data on the confounder be collected.

DECOMMISSIONING Removal of a facility (eg reactor) from service.

EFFECTIVE DOSE Effective dose is a measure of dose in which the type of radiation and the sensitivity of tissues and organs to that radiation is taken into account. The probability of a harmful effect from radiation exposure depends on what part or parts of the body are exposed. A tissue weighting factor (wT) is used to take this into account. The unit of effective dose is the sievert (Sv).

EFFLUENT A discharge of liquid waste, as from a factory or nuclear plant.

EPIDEMIOLOGY The study of factors affecting health and illness of populations, regarding the causes, distribution and control.

FISSILE (Of an isotope) capable of capturing a neutron and undergoing nuclear fission.

FISSION The splitting of a heavy nucleus into two, accompanied by the release of a relatively large amount of energy and generally one or more neutrons. It may be spontaneous but is usually due to a nucleus absorbing a neutron.

GEO-CODE The demographic characterisation of a neighbourhood or locality.

GEOGRAPHICAL (ECOLOGICAL) STUDY An epidemiological study in which the frequency of disease (or death) is observed in different areas and the locations of these areas are then related to putative sources of risk of the disease. In effect, the location and other attributes of the area are imputed to the cases without any possibility of distinguishing between them.

GRAY (Gy) The international (SI) unit of absorbed dose: one gray is equivalent to one joule of energy absorbed per kilogram of matter such as body tissue.

HAEMATOLOGY The branch of medical science concerned with diseases of the blood and blood-forming tissues.

HAZARD A property that in particular circumstances could lead to harm, eg exposure to radiation leading to damage to an individual's health.

HEALTHY WORKER EFFECT a bias in occupational epidemiology studies that is typically characterized by lower relative mortality and morbidity rates from all causes combined and from selected causes in an occupational cohort, possibly masking an increased risk of the disease under study.

HOT PARTICLE A microscopic piece of radioactive material that can become lodged in living tissue and deliver a concentrated dose of radiation to a small tissue volume.

HYPOCENTRE The point on the earth's surface vertically below the detonation of a nuclear weapon.

INCIDENCE The number of instances of illness commencing, or of persons falling ill, during a given period in a specified population. More generally, the number of new events, eg new cases of disease in a defined population, within a specified period of time. The term incidence is sometimes used to denote 'incidence rate', i.e. the number of cases divided by the (average) number at risk in the relevant time period.

INHOMOGENEITY Unevenness in distribution

INTRACRANIAL Within the skull. INTRASPINAL Situated within, occurring within, or introduced into the spinal column and especially the vertebral canal.

IONISING RADIATION- **See separate section below - Appendix 5.**.

ISOTOPE one of two or more forms of the same chemical element. Isotopes may or may not be radioactive. See https://www.sciencedirect.com/topics/earth-and-planetary-sciences/isotope for more detail.

LANGERHANS CELL HISTIOCYTOSIS (LCH) A rare disease involving clonal proliferation of Langerhans cells, abnormal cells deriving from bone marrow and capable of migrating from skin to lymph nodes. Clinically, its manifestations range from isolated bone lesions to multi-system disease.

LET / LINEAR ENERGY TRANSFER The amount of energy an ionizing particle transfers to the material traversed per unit distance. The Wikipedia entry Linear_energy_transfer is good.

LEUKAEMIA/ALL A group of malignant diseases of the blood-forming tissues in which normal control of cell production breaks down and the cells that are produced are abnormal. Leukaemia can be classified as lymphoid or myeloid and as either acute or chronic (eg ALL, AML, CLL and CML). Lymphoid and myeloid refer to the type of white cell affected. If this is a lymphocytic cell the condition is called lymphocytic or lymphoblastic leukaemia. Myeloid leukaemias affect any of the other types of white blood cells or the red cell or platelet producing cells. Acute leukaemias develop quickly and progress rapidly; chronic leukaemias are slower to develop and slower to progress. Acute lymphoblastic leukaemia (ALL) is subdivided into three types using the FrenchAmerican-British classification of: L1 Small monotonous lymphocytes L2 Mixed L1- and L3-type lymphocytes L3 Large homogeneous blast cells Each subtype can be further classified by immunophenotyping, with two main immunological types: pre-B-cell and pre-T-cell. The mature B-cell ALL (L3) is now classified as Burkitt's lymphoma/leukaemia. Subtyping helps determine the prognosis and most appropriate treatment for ALL.

LINEAR RISK SCORE A test statistic designed to determine whether a group of cases are closer to a particular point (such as a nuclear power plant) than would be expected given the population distribution in the area. It simply scores each case with a suitable measure of proximity, such as the reciprocal of distance, and adds the scores over all cases, comparing this with the value that would be expected for a random sample from the population.

LSS (LIFE SPAN STUDY) The study of the health of the Nagasaki and Hiroshima nuclear bomb survivors.

LYMPHOMA A malignant tumour of the lymphatic system (lymph nodes, reticuloendothelial system and lymphocytes).

MALIGNANT Synonymous with cancerous. Malignant neoplasms or tumours can invade and destroy other tissues and spread to other parts of the body via the bloodstream or lymphatics (metastasis).

MEGAWATT (MW) A unit of power (106 watts). MWe refers to the electrical output of a generator; MWt to the thermal output from a reactor or heat source.

MELODI The MELODI Association acts at a high level between member nations of EURATOM (one of the founding treaties of the European Union) and members of the European Free Trade Association (EFTA). It exists to coordinate and promote research and "long term competence" on the human health risks associated with low-doses of ionising radiation. It acts at the level of governments in its member nations and at the level of EU institutions, particularly the European Commission. [see Statutes on http://www.melodi-online.eu/]

META-ANALYSIS A statistical analysis used to combine the results of several studies addressing a set of related research hypotheses, usually conducted to pool findings and incorporate information from small studies with low power. It can test whether the study outcomes show more variation than expected owing to population differences and different study designs.

MONOTONIC Consistently increasing or decreasing in value.

MYELODYSPLASIA Disorders of myeloid cells of the bone marrow, either in number or degree of maturity.

NEOPLASM An abnormal growth of tissue in animals or plants, such as a tumour. Neoplasms can be benign or malignant.

NEUTRON An uncharged subatomic elementary particle. Solitary mobile neutrons travelling at various speeds originate from fission reactions.

NOBLE GASES Any of the six gases helium, neon, argon, krypton, xenon and radon, that do not react chemically with other substances except under certain special conditions. Also called inert gases.

NON-HODGKIN LYMPHOMA (NHL) A group of lymphomas that differ in important ways from Hodgkin lymphoma and are classified according to the microscopic appearance of the cancer cells. In children, NHL and leukaemias are often combined due to historical difficulties in making diagnostic distinctions.

NON-PARAMETRIC No assumptions are made about the population from which the data are drawn.

NRPB National Radiological Protection Board, set up by the UK Parliament's Radiological Protection Act 1970. In 2003 it became part of the Health Protection Agency (HPA). In HPA became the Centre for Radiation, Chemical and Environmental Hazards (CRCE), part of Public Health England, an executive agency of the Department of Health.

NUCLEAR REACTOR An engineering construction in which a nuclear fission chain reaction occurs under controlled conditions so that the heat yielded may be harnessed or the neutron beam utilised.

NULL HYPOTHESIS The statistical hypothesis that one variable has no association with another variable or set of variables, or that two or more population distributions do not differ from one another.

ODDS RATIO The ratio of the odds of an event occurring in one group to the odds of it occurring in another group.

ONCOLOGY The branch of medicine that deals with tumours, including study of their development, diagnosis, treatment and prevention.

ORDER OF MAGNITUDE A broad-brush term used to express the range of numerical expressions where it isn't possible to be precise. For example, two orders of magnitude covers the range 100 to 999.

P-VALUE The probability that, under a given null hypothesis, a particular test statistic would have, purely by chance, a value at least as disparate with the hypothesis as that observed. A P-value provides an idea of the strength of the evidence against the null hypothesis. A low P-value points to rejection of the null hypothesis. For a significance test at the 5% level, any result giving a P-value less than 0.05 would be regarded as significant and lead to rejection of the null hypothesis in favour of an alternative hypothesis. Its interpretation depends on the plausibility of available alternative hypotheses or explanations.

PAEDIATRIC Of or relating to the medical care of children.

PARTICLES This is one of the most confusing terms in this topic. "Particle" may be referring to fragments of material like uranium oxide or plutonium from nuclear reactors or bombs. Such material contaminates the environment and may become sources of internal radiation exposure following inhalation, ingestion or absorption. "Particulate matter" or "particulates" are synonyms for "particle" in this sense. "Particles" also refers to the agents by which radiation affects matter. These are subatomic particles (see *Ionisation* and *Ionising radiation types*). This report sets out to use "subatomic particles" where that sense is meant. The exception is where in quotations appear, especially quoting Professor Goodhead in section 10. In those cases "particles" is often qualified by having the term "track" close by, because "radiation" only exists as "tracks" and Goodhead's topic was track structure.

POISSON DISTRIBUTION The Poisson distribution is a probability distribution describing the numbers of events happening independently of one another, eg the number of cancers within an area. The mean and variance of counts that follow the Poisson distribution are equal.

POPULATION MIXING The population-mixing hypothesis proposes that childhood leukaemia can be a rare response to a common but unidentified infection (hence the absence of marked space–time clustering). Epidemics of this (mainly sub-clinical) infection are supposedly prompted by influxes of people into rural areas, where susceptible individuals are more prevalent than the average. Such influxes would increase population density and hence the level of contacts between susceptible and infected individuals, thereby increasing the risk of childhood leukaemia.

PROBABILITY A measure of how likely an unpredictable event is to occur on a given occasion. Mathematically it is measured on a scale of zero to one, which may be expressed as a percentage. Its usefulness in statistics stems from the fact that it can be estimated from the proportion of corresponding outcomes in repetitions of the same experimental or observational situation, and this estimation becomes more precise as the number of repetitions increases.

RADIATION/RADIOACTIVITY The emission and propagation of energy by means of rays or waves or sub-atomic particles. **See separate section below - Appendix 5.**

RADIONUCLIDE A type of atomic nucleus which is unstable and which may undergo spontaneous decay to another atom by emission of ionising radiation (usually alpha, beta or gamma).

RBE/RELATIVE BIOLOGICAL EFFECTIVENESS the ratio of **biological effectiveness** of one type of ionizing radiation **relative** to another, given the same amount of absorbed energy.

RECALL BIAS A source of bias due to differential recall by cases and controls. In many case–control studies retrospective information is obtained by interviewing the subjects or their relatives. People with a particular disease or condition may have thought a lot about a possible link with past events, especially with respect to widely publicised risk factors. Their

recall of past events may consequently differ from that of people without the disease or condition under study.

REGRESSION COEFFICIENT The slope of the straight line that most closely relates two correlated variables.

RELATIVE RISK (RR) A ratio of the risk of disease or death among those exposed to a potential hazard to the risk among those not exposed to the hazard.

RETINOBLASTOMA A common childhood malignancy of the eye that develops from retinal cells.

RISK A combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence. See HAZARD and RELATIVE RISK. Risk is sometimes taken to mean the probability that an event will occur, eg that an individual will become ill or die within a stated period of time or age. Risk is also used as a non-technical term encompassing a variety of measures of the probability of a (generally) unfavourable outcome.

SI The International System of Units is the standard modern form of the metric system. The name of this system can be shortened or abbreviated to **SI**, from the French name SI ***S****ystème* ***I****nternational d'unités*.

SIEVERT (Sv) The international (SI) unit of effective dose obtained by weighting the equivalent dose in each tissue in the body with ICRP-recommended tissue weighting factors and summing over all tissues. Because the sievert is a large unit, effective dose is commonly expressed in millisievert (mSv) – ie one-thousandth of one sievert. The average annual effective radiation dose received by members of the public in the UK is around 2.7 mSv.

SIGNIFICANCE TEST A formal procedure for assessing the evidence against a null hypothesis, specified in advance. The formal version results either in rejection of the null hypothesis in favour of some alternative, or in its acceptance. A test is associated with a 'significance level', which is the probability that this rejection would occur by chance when the null hypothesis is true. Typically this significance level is chosen to be 5%, but the choice is entirely arbitrary. In a less formal version of the significance test a P-value is calculated. Data that result in the rejection of a hypothesis at a given significance level, or equivalently in a P-value less than such a level, are described as being 'statistically significant' at this level.

SOCIO-DEMOGRAPHIC A population variable relating either to intrinsic properties of an area, such as population density, or to the average of some personal characteristic of the inhabitants, such as age, socioeconomic status or degree of household overcrowding.

SOCIOECONOMIC STATUS A measure related to levels of living or social class. It may apply to individuals or groups. In this report it is applied to the populations of census wards or county districts, and is based on information from the 1981 census.

STANDARDISED INCIDENCE RATIO (SIR) The ratio of the actual number of cases in a study group or population to the expected number. The expected number is calculated using the age- and sex-specific incidence rates for a reference population. These 'reference rates' will often be those of the national population but may also be taken from a smaller area.

STANDARDISED MORTALITY RATIO (SMR) The standardised incidence ratio for the deaths in a study group or population.

STATISTICAL SIGNIFICANCE The likelihood that a relationship between two or more variables is caused by something other than chance.

TRACK – See particles.

TREND The tendency for the values of a variable to increase or decrease as some other variable – most commonly time – changes.

Appendix 6 Radioactivity and Radiation

The purpose of this report does not require detailed definitions of either radioactivity or radiation. The whole topic of radiation protection is however marked by loose terminology, even in encyclopaedias and specialist web sites, and by confused usage. So some discussion is needed to enable non-specialist readers to follow the argument.

Radioactivity is an instability in some atoms, so that the nuclei of those atoms have a possibility of changing ("decaying") by emitting "radiation", which is a form of energy.

Radiation is the emission or transmission of energy in the form of waves or subatomic particles through space or through a material medium. Radiation is often categorized as either ionising or non-ionising depending on its energy. Non-ionising radiation includes radio waves, microwaves, infrared, visible light, and ultraviolet.

Irradiation (sometimes mistakenly used as a synonym for radiation) To irradiate something is to expose it to radiation. Irradiation is the act of irradiating something, or the condition of being irradiated.

Ionising radiation (**IR**) Radiation from the decay of atoms is generally ionising due to its highly energetic nature — more than 10 eV — which arises from the strength of atomic bonds. It may comprise any of the following subatomic particles: photons, electrons, positrons, helium nuclei, neutrons, protons, neutrinos, anti-neutrinos. The types relevant to non-specialist discussions of radiation protection are classified as gamma (which are high energy photons), X-rays (less energetic photons), beta (electrons), and alpha (helium nuclei).

Ionisation When subatomic particles with energies greater than about 10 electron volts (10 eV) hit an atom, one or more electrons may be knocked out of their orbits around the atom and escape, thus becoming "ions" and leaving the atom in an "ionised" or "excited" state. Ions and ionised atoms are highly reactive, which is why they cause further ionisations. Deleterious biological effects occur when subatomic particles passing through body tissue ionise components of cells causing damage which is not successfully repaired.

Ionising radiation types

Most descriptions of ionising radiation discuss different types — alphas, betas, gammas, X-rays, neutrons, and cosmic rays including extraterrestrial X-rays.[49] There is no useful purpose in rehearsing this information here as it can be found in many places and, in the radioprotection context, is uncontentious. It is, however, necessary to outline how the types differ.

Gammas, which are photons, travel at close to the speed of light and have no electric charge and virtually no mass/momentum. These factors mean that gammas interact with matter relatively rarely, which explains why they are highly penetrating.

Alphas At the opposite end of the IR segment of the electromagnetic spectrum, alphas are the nuclei of helium atoms. Compared with gammas they have massive momentum and very high cross section. They therefore interact with matter intensely, giving up their energy in the form of large numbers of ionisations and slowing down so rapidly that they cannot penetrate the layer of dead cells on human skin. In fact what has happened is that each helium nucleus has captured two electrons and has become an inert helium atom, leaving a lot of ionised and excited atoms in its wake. All the immediate damage from alpha decays in living tissue is contained within a few cell diameters of the source (e.g. a fragment of uranium or plutonium). A large proportion of the affected cells die; any health effects will be caused by damage that is survivable but misrepaired.

[49] For the sake of completeness it should be noted that cosmic rays other than X-rays hitting the earth's atmosphere consist of the nuclei of any naturally-occurring element including uranium. Cosmic rays and extraterrestrial X-rays do not directly affect life at ground level but are absorbed by the upper atmosphere, resulting in energetic secondary radiations which are classified as gammas and which do reach the ground because they are highly penetrating. This contributes a significant proportion of the naturally occurring ionising radiation that is generally called "natural background".

Beta particles are negatively charged high energy electrons emitted alongside a proton when a neutron-rich nucleus splits. Betas lie between alphas and gammas in terms of their ability to penetrate and interact with matter.

Non-ionising radiation also has biological effects but, since it has less energy, the effects tend to result from its influence on the bonds between atoms in molecules rather than bonds between the constituent parts of atoms, which are far stronger. The boundary lies roughly between X-rays (generally ionising) and low frequency ultraviolet (non-ionising). Non-ionising radiation is not discussed in this report.

Appendix 7 Brief biographies of the authors

Richard Bramhall

In 1993, Richard began researching the health effects of radioactivity in the environment initially concentrating on the aftermath of the Chernobyl accident in 1986. Particularly, he became concerned about the regulatory and policy implications of conceptual flaws in the prevailing risk model of the International Commission on Radiological Protection (ICRP), and about the circularity of arguments put forward by various agencies in defending ICRP's recommendations. In 1996, he and Dr Chris Busby established the Low Level Radiation Campaign of which Richard is the Company Secretary.

In 1997 Richard analysed European Commission proposals for a significant relaxation of the quantities and concentrations of radioactivity permitted in recyclable and reusable materials arising on nuclear licensed sites; his campaign materials led to an international movement against the proposals, and several EU member states including UK retained pre-existing and more precautionary standards.

Since then Richard has participated in many dialogues with the nuclear industry, its regulators, and other agencies and advisers. He was a steering group member of the long-running SAFEGROUNDS dialogue (1999-2012), developing good practice guidance for the management of contaminated land. In 2001 the Environment Minister, the late Michael Meacher MP, and Health Minister Yvette Cooper MP set up the Committee Examining Radiation Risks of Internal Emitters (CERRIE) to scope and report on areas of disagreement concerning risk estimates for exposure to ionising radiation. Both Dr Busby and Richard were invited to be members. The Committee failed its remit of producing a unified report explaining unresolved topics and a Minority report was published in 2004 detailing his concerns. He continues to work on defining the conceptual flaws in the official radiation risk model in terms comprehensible to non-experts and to counter the attempt to dismiss still-emerging evidence of illness caused by nuclear weapons tests and Chernobyl and, more recently, Fukushima. Full CV available on request.

Pete Wilkinson

Pete Wilkinson is a veteran environmental campaigner who co-founded Friends of the Earth and Greenpeace UK in the 1970s. During his fifteen years with Greenpeace UK during which time he held the positions of Director, Campaigns Director and International Board member, he was responsible for planning and executing what one journalist described as ‘some of the most imaginative and successful environmental campaigns of the 80s’. Among the successes Greenpeace achieved on his watch were an end to radioactive waste dumping in the Atlantic, a ten-fold reduction in the discharges of alpha-emitting waste from Sellafield into the Irish Sea, a ban on commercial whaling, dolphinaria and fur farms. His tenure culminated in leading six expeditions to Antarctica, triggering its protection from mining extraction at least until 2041. On leaving Greenpeace, he set up his own environmental consultancy and specialised in stakeholder engagement and facilitation helping to bring opposing parties to the table to narrow polarised views around controversial issues such as nuclear waste management and electromagnetic fields. He advised government departments and was appointed to the Committee on Radioactive Waste Management. He is chair of a group fighting the development of Sizewell C in Suffolk, deputy chair of the Sizewell Site Stakeholder Group, is a popular public speaker, author of two books and regularly takes part in meetings with nuclear regulators. Full CV available on request.

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