Low Level Radiation and Health Conference
Silver Anniversary CONFERENCE 1985-2010

Final Report

Quaker Meeting House
Manchester
June 19th, 2010
An introduction

The International Standing Conference on Low Level Radiation and Health was initiated in 1985 by a local voluntary group, the Severnside Campaign Against Radiation (SCAR) which is based in Gloucestershire. The aim of that meeting was to bring together experts willing to help local people understand the incidence of childhood cancer found in their area. The event run by volunteers celebrated its 25th Silver Anniversary in 2010.

This unique Conference has relied on local groups or organisations to host it in different parts of the country each year. It has successfully brought together members of the nuclear industry, Government organizations, radiation protection and monitoring agencies, Local Authorities, medical experts, academic researchers, campaigners and local interested members of the public to share knowledge, experience and opinions. It is designed to involve people as much as possible with a blend of platform presentations and workshop sessions where issues can be addressed in more detail.

The conference has been instrumental not only in making issues more accessible to a wider audience but it has also played a role in highlighting research at an early stage which has subsequently become an influential part of the picture. In this context there have been workshop sessions on Radioactivity and Wildlife (Dr Janet Rowe, Bristol, 1991) an issue which has been under much discussion by the institutional radiation protection framework since 1999; Research on genomic instability (Professor Eric Wright, Liverpool, 1993, 1995 and 2010) or the Bystander Effect (Dr Carmel Mothersill, Greenwich 1998; 2008 and 2010).

The programme for 2010 featured the latest research and developments concerning:

- Radiation Risks
- Managing Radioactive Wastes

The UK and Ireland Nuclear Free Local Authorities (NFLA) was established in November 1980 and reaches its 30th anniversary this year. It is the primary local government organisation working on nuclear issues. It takes a leading role within local government and lobbying central government on nuclear power, nuclear safety and nuclear weapons proliferation issues. It seeks to build a nuclear weapons free world, and is a close partner of the Hiroshima and Nagasaki led Mayors for Peace. It also opposes expansion of the nuclear fuel cycle - seeing renewable energy, microgeneration and energy efficiency as cleaner and more sustainable alternatives.

The NFLA has taken a continuing interest in the technical, political and scientific debate on the effects of low level radiation on health and has produced many policy briefings and supported considerable independent research on this important issue. It has recently submitted to the Government its concern on the effects of low level radiation around nuclear sites and urged the UK Government to lengthen the consultation on the justification of new nuclear power stations to adequately consider the findings of the COMARE commission into the German government's KiKK report. It campaigns for public safety, health and environmental protection.
PRESENTATIONS

• Alice Stewart lecture
  o Childhood leukemia in the vicinity of German Nuclear Power facilities - results and consequences of the KiKK study. Abstract and author’s biography, Professor Wolfgang Weiss given at the Conference by Dr Alfred Koerblein (a member of the German study expert group).
  o Shape of the dose-response relationship and its impact on leukemia risk by Dr Alfred Koerblein

• Radiation Risks
  o Radiation-induced bystander effects – latest news by Professor Carmel Mothersill (McMaster University, Canada)
  o Radiation biology of environmental and medical exposures, Professor Eric Wright (University of Dundee)

• Managing Radioactive Wastes
  o Geological Repository – the holes in the argument, Dr Rachel Western, Former nuclear researcher Friends of the Earth and NIREX
  o UK Uranium supplies: health and environmental impacts Peter Diehl, WISE Uranium website

WORKSHOPS

Forgotten Heroes? A Case Study of Britain’s Cold War Atomic Test Veterans and the Burden of Proof. Tracey Morris, University of St Andrews
Very low levels of radiation and health effects, John Urquhart, PhD student, OU

RECENT RELEVANT RESEARCH PAPERS

• Three Mile Island – A Chronology of Health Problems related to Three Mile Island

OBITUARY

• Dr Philip Day, Reader in Chemistry, Manchester University, by Robert G. Denning and Deborah Oughton, J of Radiol Prot 30 (2010) 103-104 with kind permission from the publishers
PROGRAMME

Saturday 19th, 2010

9.30-10: Registration
10.00  Welcome to Manchester
       Session Chair: Sean Morris, NFLA secretary

ALICE STEWART LECTURE
10.10  Childhood leukemia in the vicinity of German Nuclear
       Power facilities - results and consequences of the KiKK
       study.  Professor Wolfgang Weiss (German Federal Office
       for Radiation Protection)

10.55  Questions and Answers

Theme 1: Radiation Risks

11.10  Shape of the dose-response relationship and its impact on
       leukemia risk, Dr Alfred Koerblein (Environmental Institute,
       Munich)

11.30  COFFEE

11.50  Radiation-induced bystander effects – latest news
       Dr Carmel Mothersill (McMaster University, Canada)

12.10  Radiation biology of environmental and medical exposures
       Professor Eric Wright (University of Dundee)

12.30 – 1.00 Questions and discussion

1.00-2.00  LUNCH

2.00:  Workshops:

➢ Very low levels of radiation and health effects, John Urquhart,
       PhD student, Open University
➢ Forgotten Heroes? A Case Study of Britain’s Cold War
       Atomic Test Veterans and the Burden of Proof. Tracey Morris,
       University of St Andrews

3.30:  TEA

4.0  Theme 2: Managing Radioactive wastes
    Session Chair: Pete Roche, Energy and Environment Consultancy
    Edinburgh
    Geological Repository – the holes in the argument
    Dr Rachel Western, Former nuclear researcher Friends of the Earth
    and NIREX

4.20  UK Uranium supplies: health and environmental impacts
       Peter Diehl, WISE Uranium website

4.40-5 Questions and discussion

7.00     Evening meal and social, pub Briton’s Protection, 50 Gt
         Bridgewater St, Manchester M1 5DL.
Alice Stewart Lecture

Abstract

Childhood leukaemia in the vicinity of German Nuclear Power Facilities – results and consequences of the KiKK study

Wolfgang Weiss,
Federal Office for Radiation Protection, Germany
Head of Department Radiation Protection and Health

State of knowledge

The incidence rates (SIR) of childhood leukaemia in Germany are well documented by the German Childhood Registry. The most recent figures are: 1800 leukaemia cases are registered every year in Germany in children up to the age of 15 years. This number corresponds to 0.2% of all children in this age group; the nominal incidence rate is 5 cases per 100,000 children per year. During the past 10 years (1999-2008) leukaemia contributed about 34% to the total number of all childhood cancers registered in Germany. A pronounced age dependence of the incidence rates is observed with a maximum between the age of 2 and 5 years. Little if any differences are observed between boys and girls. The geographical variations of the incidence rates observed in Germany are documented by the German Childhood Registry as averages of 328 districts. Generally the maps show a very heterogeneous pattern. There is no north-south trend nor an east-west trend and no group of districts with elevated incidences. During the most recent time period, 14 of the 328 districts show a formally ‘noticeably increased SIR, while 7 have a ‘noticeably decreased’ one. There are not more districts with noticeable increased incidence rates than would be expected given statistical variation (assuming a Poisson distribution).

Despite intensive research efforts, the detailed mechanisms as well as the causation of cancer initiation and development are unknown. The scientific literature discusses quite a number of risk factors which could initiate or promote cancer development. For childhood leukaemia this list includes ionising and non-ionising radiation, the genetic as well as the immune status, various chemicals, birth weight and socio-economical factors (for details see [6]). At present, only ionising radiation (above a certain level of dose) and genetic factors are considered to be proven risk factors for childhood leukaemia. The observed incidence rates can by far not be explained by adding up all known and postulated risk factors identified so far. This can only be explained by assuming that either a major risk factor has not been identified yet or that the known risk factors interact in a non-linear fashion.

The KiKK study

The epidemiological study on childhood cancer in the vicinity of nuclear power plants in Germany (KiKK) shows that the cancer risk, especially the leukaemia risk of children below the age of five years increases with increasing proximity to the site of a nuclear power plant. Details are given in the Annex 1 which is a compilation of the final report of the Study Group (German Childhood Cancer Registry).

Earlier ecological studies had found an increased leukaemia risk in children under five years within the five kilometre radius. The case-control design used for the KiKK study provides results which are more reliable. A clear negative trend could be ascertained indicating that the risk increases with increasing proximity of the place of residence of the children relative to the site of a nuclear power plant. Furthermore, the elevated risk was observed in the entire study region, i.e. also outside the 5-km radius. It was not possible to determine individual radiation exposures of the more than 6000 children which were included in the study. The distance
between the site of the nearest nuclear power plant and the place of residence was used as a substitute for both cases and controls, respectively.

The study also took into account other risk factors with known or assumed carcinogenic effects. No indication was found that the result could be explained by a risk factor other than the vicinity to the nearest nuclear power plant. The clear dependence of risk on the distance from the sites is indicative for a potential causal relationship, however this is no proof. This result of the KiKK study has caused controversial discussions which are ongoing.

The KiKK study was evaluated by a group of three epidemiologists, who were members of the Study’s Expert Group, and by the German Commission on Radiological Protection (for details see reference 5 and Annex 2). Both evaluations concluded that the study was conducted according to the Good Epidemiological Practice and that the results were calculated correctly. Further analyses were conducted by the study team based on the data set indicating that the increased risk of childhood leukaemia near NPPs might be restricted to the near-field of the reactors, but it is impossible to define the size of the near-field.

The way forward

Due to the still unresolved issue of causation, BfS is in progress of developing a research agenda which will put emphasis on the investigation of the causes of childhood leukaemia, which of course has to be done in a multidisciplinary fashion. Research has to focus on gene-environment interaction and has to take into account other possible environmental carcinogens, too, not only ionizing radiation, e.g. non-ionizing radiation, pesticides, etc..

References

Annex 1: Background of the KiKK-Study

The German Childhood Cancer Registry (DKKR) carried out an epidemiological case-control study which started in 2003 and was intended to find out whether cancer in children under 5 years of age is more frequent in the immediate vicinity of nuclear power plants (NPP) than further away.

This study was motivated by a series of exploratory evaluations of former studies conducted by the DKKR using a different method estimating the cancer incidence of children near German NPPs. This was followed by exploratory analyses of data from the DKKR carried out by third parties based on data sets used and published by the Federal Office for Radiation Protection (BfS) for their studies, mainly for the purpose of environmental health reports. The present study consists of two parts: Part 1 is a case-control study without case or control contact, whereas for Part 2 interviews were carried out in a subgroup of cases and controls from Part 1. The study design was defined in consultation with an Expert Committee assembled by the BfS. The hypothesis of the study (in terms of the statistical null hypothesis) is: "There is no relation between the vicinity of a residence to a NPP and the risk of cancer up to the 5th year of life. There is no negative trend of the disease risk with distance".

Material and Methods

A case-control study was carried out. Part 1 includes all cases of children reported to the German Childhood Cancer Registry, diagnosed with cancer between 1980 and 2003, who were under 5 years of age at the time and living in pre-assigned regions around 16 German nuclear power plants (1,592 cases). Controls of equal sex and age in the year of the diagnosis of the disease were chosen randomly for each case (4,735 controls). The individual distance of the residence was determined on the day of diagnosis for the cases, and on a corresponding reference date for the controls.

For Part 2 of the study, a subgroup of cases and controls from Part 1 was questioned about potential risk factors which might act as confounders and about their residence history. For this purpose, the cases diagnosed between 1993 and 2003 who were less than 5 years of age, affected by leukaemia, lymphoma or a CNS tumour, and living in the study region at the time of the diagnosis were selected. The controls assigned to theses cases in Study Part 1 were also used in Part 2.

Results

Data

The appropriation of the addresses of cases and controls and their geological coding could largely be carried out as scheduled. There was only very little missing or inaccurate information. The predefined accuracy of at least 100 m for the distance to be determined between dwellings and the nearest NPP was fulfilled to an estimated average accuracy of approximately 25 m.

Control recruitment showed that communities in the vicinity of NPPs were less cooperative in providing control addresses (84 per cent control addresses provided, compared to 90 per cent elsewhere) than those further away. 78 per cent of the cases and 61 per cent of the controls were willing to participate in the survey in Part 2. The case-control relationship of 1:2 which had been targeted was achieved.

For a random sample of participants the information given was validated by comparing it with copies of medical records (maternity card, check-up pass, vaccination pass). The statements concerning vaccinations and data relevant to childbirth (body weight and height at birth, week of pregnancy at birth) proved to be consistent with the records.

A comparison of survey participants and non-participants revealed that participation of families was less frequent when the specific day in question (time of diagnosis for case children, corresponding reference day for control children) was longer ago (1993-1995, i.e. about 10 years before the interview). The most obvious
influence on the willingness to participate proved to be the distance from the nearest NPP: within the inner 5-km area the willingness to participate was considerably lower, and this was even more pronounced in controls (46 per cent within the area compared to 62 per cent outside of it) than in cases (63 per cent compared to 79 per cent outside). We conclude that families living in the immediate vicinity of a NPP are very well aware of this fact and, therefore, tend to be more reticent when questioned.

A short questionnaire was sent to all potential participants in the survey of Part 2. Families of higher social status appeared to be more willing to participate, especially in controls. This phenomenon is known from other epidemiological and empirical studies (in Germany and internationally).

**Confirmatory analysis**

The main hypothesis for Part 1, i.e. that no monotonic decreasing relation exists between the distance of the dwelling from the next NPP and the risk of disease, was rejected at the one-sided level = 5 per cent. 1/r was predefined as a distance measure, whereby r is the distance between the home address and the nearest NPP. Regression analysis resulted in an estimate for the regression coefficient of \( b^* = 1.18 \) (lower one-sided 95-per-cent confidence limit = 0.46, i.e. statistically significant different from zero). Evaluation of the secondary question, for which the distance is considered as a categorical variable, also shows a statistically significant result (estimated Odds Ratio (OR) = 1.61, lower one-sided 95-per-cent limit = 1.26) for the 5-km area around the NPPs.

In the diagnostic subgroups, leukaemia (593 cases, 1,766 controls) showed a statistically significant estimate of the regression coefficient of \( b^* = 1.75 \) (lower onesided 95-per-cent confidence limit = 0.65). The effect observed in the subgroup of all leukaemias is stronger than that of all malignancies. The leukaemia subgroups in the study each exhibited similar values. However, this is only statistically significant in the case of acute lymphatic leukaemia. The number of cases of acute myeloid leukaemia was too small (75 cases, 225 controls). In the other predefined diagnostic subgroups (CNS-tumours, embryonal tumours) there was no evidence of distance dependency. It may be concluded that the effect observed in all malignancies is mainly due to the results of the relatively large subgroup of leukaemias. There is no statistically significant difference between the regression coefficients in the predefined subperiods (first half of the prevailing reactor life span compared to the second half) \( p=0.1265 \).

The members of the subgroup of cases and controls contacted in Part 2 of the study (471 cases, 1,402 controls) show no relevant difference with respect to the regression parameter determined for the whole group in Part 1 (estimated coefficient 11 per cent less than overall model). However, the group of people participating in the interview differs considerably from the complete group.

A statistical criterion was defined in the analysis plan to determine whether the participants in the telephone interview (Part 2) were possibly a non-representative selection of the cases with corresponding diagnoses from Part 1 and the controls related to them. In which case the results of Part 2 could not be used to interpret the results of Part 1. This criterion was fulfilled, i.e. the data from the interviews in Part 2 of the study cannot be used to check whether the results of Part 1 have been biased by potential confounders. The reason is mainly based on reluctance to participate within the inner 5-km-area.

**Sensitivity analyses and explorative analyses**

A series of sensitivity analyses and exploratory analyses was carried out, some of which were planned whereas others resulted from the data situation. On the whole there was no evidence of any relevant influence on the results. Most of the sensitivity analyses tend to show a slight overestimation of the effect reported.

The planned exploratory analyses of the shape of the regression curve using fractional polynomials and a Box-Tidwell-Model showed no evidence of a basic difference of the shape of the regression curve to that intended in the analysis plan. Since the provision of control addresses by the communities in the vicinity of NPPs was less
exhaustive than by the more remote communities, a sensitivity analysis was carried out in addition to the specifications of the analysis plan. The potential bias due to this problem of control recruitment is minimal.

Interviews on residence history (Part 2) revealed that some of the control families had only lived at the originally registered addresses after the day of reference and at no time before it. This is because incorrect control addresses had been provided by the registration offices. Simulations, an extended evaluation of control recruitment data, and verification in a random sample of community registration offices showed that this was of only marginal influence on the result of the study. Omitting one NPP region at a time (for all malignancies and leukaemias, respectively) showed no indication that the result depends solely on one individual region. It should be noted, with regard to the heated discussion in Germany on the increased incidence of leukaemia in children living near the NPP Krümmel (as a result of 17 cases of leukaemia between 1990 and 2006 in two neighbouring communities), that 8 of these cases are within the inner 5-km study area. As regards leukaemia, the NPP Krümmel has the biggest influence on the result of the study. If these cases and the corresponding controls are omitted, the estimate for the regression coefficient in the subgroup of leukaemias is $b^* = 1.39$ (lower one-sided 95 per-cent confidence limit=0.14).

**Confounder Analyses**
The results of Part 2 cannot be used to interpret the results of Part 1, because a selection occurred, as willingness to participate depended on the distance between the home and the NPP. Nevertheless, a multivariate regression analysis was carried out on the request of the BFS and the Expert Commission using the data collected (confounder analysis). The question of whether allowance for potential confounders would change the estimated regression coefficient of the distance measure was looked into (change-in-estimate principle), as originally intended. This had been the motivation for conducting Part 2 of the study. None of the variables led to changes in the estimate which exceeded the preset range ($±1$ standard deviation). An exploratory evaluation of the confounders which this study, however, was not designed for, revealed correlations which largely confirmed the results known from literature.

**Attributable Risks**
The risk attributable to living within a 5-km area of one of the 16 nuclear power plants in Germany between 1980-2003, and for the number of cases observed in the 5-km area under study (n=77) is 0.2 per cent. This means that under the model assumptions, 29 of the 13,373 cases diagnosed with cancer at less than 5 years of age from 1980 to 2003 in Germany, i.e. 1.2 cases per year, could be attributed to living within the 5-km area of a German NPP. In relation to the cases of leukaemia, of which 37 were observed at up to 5 years of age between 1980 and 2003 within the inner 5-km area, a 0.3 per-cent population attributable risk was calculated, i.e. 20 of 5,893 cases under 5 years of age in Germany which were diagnosed between 1980 and 2003, making 0.8 cases per year. These estimates are rather inconclusive because they are based on a very small number of cases.

**Discussion**

**Study design**
This Study is a case control study on children of less than 5 years of age who were diagnosed with cancer between 1980 and 2003. The study investigated the question of whether there is a relationship between the distance from the residence to the nearest NPP and the risk of developing cancer. The strength of this study is its application of an individual distance measure, based on the distance between homes and the nearest NPP. It thus complements the NPP studies which have been conducted in Germany up to now based on aggregated incidence rates in vicinity regions.

The interviews of a pre-selected subgroup of parents of case and control children integrated into the study were intended to take potential confounders into consideration in order to use this information for the evaluation of the study result. This analysis was unfortunately not possible, or rather could not be evaluated because of the
participants’ response behaviour. There are, however, hardly any risk factors known in present literature which could act as sufficiently strong confounders.

**Radiation epidemiological aspects**

The present study considers the distance from the nearest NPP. Data on radiation exposures due to environmental conditions were not used because they are not available, nor can they be collected retrospectively. Neither was it taken into consideration that individuals do not stay in the same place constantly and that beyond the natural radiation background they are also exposed to other sources of radiation (e.g. terrestrial radiation, medical diagnostics, air travel). Varying topographic or meteorological conditions (e.g. precipitation, wind direction) could not be allowed for either.

The distance applied was that of each individual’s home from the nearest NPP at the time of diagnosis (control: date of diagnosis of matched case). Taking into account home moves during the time from conception to diagnosis would have necessitated the interviewing of the families under study and was, therefore, not possible for most of the families involved.

A distance measure based on a predefined model was decided on and a regression curve was estimated for it. The distance measure was based on theoretical dispersion models, and the regression model corresponds to the standard linear model for the low-dose range. This model however is based on studies evaluating the cancer risk in adults in relation to ionising radiation. Adults predominantly develop solid tumours, whereas systemic diseases are relatively more frequent in children. It has not so far been clarified in international literature as to what extent models describing low-dose radiation effects can be transferred to leukaemia incidence in children of pre-school age.

The estimates of low-dose radiation effects presently used on the international level are based on the assumption of a linear no-threshold extrapolation, an additional option for leukaemia is a quadratic model. Other authors suggest that these models considerably overestimate the effects in the dose range < 0.01 Sv (Sievert). Special statements about children are not made in the relevant reports, or the data is described as insufficient for this purpose. The models for example specify an excess relative risk, which could be compared with the dimension OR-1 in the current report, of 0.5 per Gy per year (one Gray (Gy) corresponds to 1 Sievert). The limit of exposure for persons in the “proximity” of nuclear technical plants in Germany is 0.3 mSv (milliSievert) per year. The effective exposure is much lower. For example, a 50-year-old living at a distance of 5 km from a NPP is expected to accumulate from 0.0000019 mSv (milli Sievert) for Obrigheim NPP to 0.0003200 mSv for Grundremmingen NPP through exposure to airborne emissions from Obrigheim and Grundremmingen, respectively. Annual exposure in Germany to the natural radiation background is approximately 1.4 mSv and the annual average exposure through medical examinations is approximately 1.8 mSv. Compared to these values, the exposure to ionising radiation in the vicinity of German NPPs is lower by a factor of 1,000 to 100,000. In the light of these facts, and based on the present status of scientific knowledge, the result of the study cannot be explained by the currents state of science in radiobiology.

**Comparison with previous German NPP-studies**

Before the present study was carried out, the German Childhood Cancer Registry had conducted two studies involving incidence comparisons in connection with NPPs. The first study (“Study 1”) considered the incidence of all the cancer cases diagnosed from 1980 to 1990 of individuals under 15, living within 15 kilometres of any of 20 German NPPs as compared to demographically similar comparison regions. The study was motivated by the conspicuous findings within a range of 10 miles of British NPPs (Sellafield, Windscale) and the main issue was to examine all children diagnosed at 0-14 years of age within a 15-km area. No increased risk was found (RR 0.97; 95-per-cent CI [0.87;1.08]). Age subgroups, vicinity regions, and diagnosis subgroups were examined by way of exploratory analysis.
The exploratory additional results were verified in a subsequent study (“Study 2”) based on the same design and using independent, updated data from 1991-1995.

The central question (all diagnoses, age 0-14, 15-km area) remained the same, the corresponding result was unremarkable (RR 1.05; 95 per cent CI [0.92; 1.20]). The significant exploratory results from the first study, especially those pertaining to the question of leukaemia in children of less than 5 years of age living within the 5-km area, then revealed slightly lower relative risks and were statistically insignificant. Consequently, this was regarded as non-confirmation of the exploratory results. The previous studies and the present study overlap with respect to the cases and the regions examined, especially in the vicinity of the NPPs. In contrast to the previous studies the BfS Expert Committee excluded the nuclear plants Kahl, Jülich, Hamm, Mühlheim-Kärlich, and Karlsruhe. These are essentially research reactors or nuclear power plants with short operating times. About 70 per cent of the cases of children under 5 years of age living within the inner 5-km area included in the present study had already been included in the previous studies 1 and 2, and 80 per cent of cases in the previous studies are included in the current study. The discrepancy is due to the exclusion of a number of nuclear plants and also to the additional time span considered (1996-2003) and the modified definition of “vicinity”.

In the previous studies, communities were assigned a 5, 10 or 15 km zone according to the location of most of their area, and no individual house coordinates were used. Similar to the result of the main question of the previous study (age up to 15 years, 15-km area), the consideration of all malignancies in children of less than 5 living within the inner 5-km areas in the first studies did not lead to the conclusion that an increased risk existed because the effect estimates were not statistically significant (two-sided tests). However, using the approach of the present study, a statistically significant increase of risk was found (one-sided test). The, at the time, most debated result obtained by exploratory data analysis in Study 1 (relatively clear increase in the risk of acute leukaemia in children under 5 years of age living within the 5-km area) is confirmed to a similar order of magnitude by the present study and on the basis of the extended time span of 1980-2003. As regards leukaemia, the influence of the previous results on the present results is very obvious. The risk estimate obtained in Study 1 for the period of 1980 to 1990 is nearly identical with that obtained for the same period in the present study. The odds ratio for the period after the two previous studies (1996-2003) is lower than that obtained for the preceding periods.

The former had been an exploratory result within Study 1 which was, therefore, less relevant than the confirmatory analyses within the same study. In the study which was intended to check this (Study 2) the significant result was not confirmed however the relative risk was increased. In the latest study the same question was examined as a secondary question, and this time a statistically significant result was obtained.

Conclusions
The present study confirms that in Germany there is a correlation between the distance of the home from the nearest NPP at the time of diagnosis and the risk of developing cancer (respectively leukaemia) before the 5th birthday. This study is not able to state which biological risk factors could explain this relationship. Exposure to ionising radiation was neither measured nor modelled. Although previous results could be reproduced by the current study, the present status of radiobiologic and epidemiologic knowledge does not allow the conclusion that the ionising radiation emitted by German NPPs during normal operation is the cause. This study can not conclusively clarify whether confounders, selection or randomness play a role in the distance trend observed.
Annex 2 (extract of ref. [5])

Report from an Independent Check on the Recently Published Paper on Leukaemia in Young Children Living in the Vicinity of German Nuclear Power Plants*

Sarah C Darby and Simon Read
CTSU, Nuffield Department of Clinical Medicine,
University of Oxford, United Kingdom

Discussion and conclusions

Independent check of the calculations
Our independent check of the calculations presented in the paper by Kaatsch et al. confirm those reported in that paper. Additional evidence that the calculations are correct is provided by a second analysis based on alternative assumptions which find the same results, and also by further sensitivity analyses.

We conclude that there is evidence of an increased incidence of acute leukaemia in children living within 5 km of a nuclear power plant. Our best estimate of the magnitude of the increase is that the odds ratio is 1.74 (95% confidence interval 1.02, 2.96). This estimate is based on 21 cases occurring in children living within 5 km of a plant over a 13-year period. Thus a total of 9 cases (ie 21 x 0.74/1.74) are attributable to the factor that is causing the increase, or just under one case per year.
We also conclude that there is no evidence of any increase in the risk of acute leukaemia in children living at distances greater than 5 km from a nuclear power plant.

Interpretation of the increase
Although the independent check confirmed the association between living less than 5km from a nuclear power plant and an increased risk of childhood leukaemia, we conclude that the increase is not causally related to radioactivity released by the power plants. Our reasons for concluding this are as follows:

• The reported releases of radioactivity from the power stations are very low. If there had been large scale unauthorised releases of radioactivity by the German power stations, we believe that they would have been detected by monitoring either of the local environment or of workers leaving the power plant. No such evidence has been reported to date.
• We believe that any exposure to ionising radiation, however, small, will cause some increase in the subsequent risk of cancer, and particularly of leukaemia. However, studies of other individuals exposed to ionising radiation, including studies of exposures that are qualitatively similar to those that arise from the generation of nuclear power, suggest that the risk to those exposed at the levels of radiation likely to occur in the local area of a nuclear power plant would be very small indeed and certainly much smaller than the increases seen in the present study.
• Studies in both Germany and the UK of children living in the areas where nuclear power plants were planned but were never built have found increases in the risk of childhood leukaemia that are similar in magnitude to those found in the vicinity of existing nuclear power plants. This suggests that nuclear power plants tend to be built in areas where the risk of childhood leukaemia is already increased for some other, and as yet unestablished, reason.

Pointers for further investigation
The increased risk of childhood leukaemia in children living near nuclear power plants in Germany, as well as near places where nuclear power plants were planned but were never built, suggests that there is indeed a causal factor present in the environment that varies in magnitude according to the location of the child’s residence. Therefore, as Independent check nuclear power plants tend to be built in rural areas more often than in urban
ones, we investigated directly the possible role of the urban/rural status of the child’s place of residence as a risk factor for leukaemia. We found that there was indeed evidence of an increased risk of acute leukaemia in children living in a rural as opposed to an urban or mixed environment. Our best estimate of the magnitude of the increase is that the odds ratio is 1.85 (95% confidence interval 1.06, 3.23). The association was stronger during the period 1991-2003 than it had been during the period 1980-1990. It affected both boys and girls and affected children aged 2-4 years more than children aged 0-1. The increased risk of childhood leukaemia associated with living in a rural area did not in itself account for the increased risk associated with living near a nuclear power plant. However, it is likely that living in a rural area is not in itself the causal factor, but that it is associated with the true, but as yet unknown causal factor. Such a factor, which must exist, may well be responsible for both associations. The estimated increase in the risk of acute leukaemia in children associated with living in a rural area is based on 94 cases occurring over a 24-year period in children living in rural areas that were included in the study. Thus a total of 43 cases (ie 94 x 0.85/1.85) are attributable to the factor that is causing the increase, or just under 2 cases per year within the study population. However, this study included only a small proportion of the German population. If the factor were also present in other rural areas in Germany, or if it affected some children living in areas that are not rural (eg those living near nuclear power plants in mixed or urban areas), then the number of cases attributable to it could be many more than this.

We conclude that future investigations of the causes of childhood leukaemia be carried out that build on the finding of an increased risk associated with living in rural areas or in areas where a nuclear power plant has been built or planned. In designing such investigations it should be noted that the causal risk factor must be either environmental or, possibly a gene-environment interaction, rather than a genetic effect on its own, as it is implausible that the rural and urban populations of Germany are materially different genetically. Furthermore, in designing such studies, it should be noted that several recent investigations of the causes of childhood leukaemia have been of limited value, as they have depended on agreement to participate in the study by the parents of both case and control children and this has not always been forthcoming, particularly as regards the control children.

Presentation

NB: The presentation was drawn up by Professor Wolfgang Weiss but his journey to the Conference was thwarted and, in the event, he was unable to attend. The paper was kindly given by another speaker, Dr Alfred Koerblein who was, himself, a member of the expert group assessing the KiK project. The Conference was extremely grateful for his assistance in this matter.

Biography: Dr. Wolfgang WEISS, Director and Professor

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1980-2000: BfS, Head of the Institute for Atmospheric Radioactivity, Freiburg

Fields of professional interest:
• Radiation effects, radiation risk, risk communication.
• Medical radiation hygiene and dosimetry.
• Occupational radiation protection.
• Non-ionising radiation.
Shape of the dose-response relationship and its impact on leukemia risk

Dr Alfred Koerblein

The most striking result of the German KiKK study is a more than two-fold increase in leukemia risk in young children living near German nuclear power plants (NPPs). The statistical significance of this finding is such that a chance result can be largely ruled out. No other potential risk factor was identified in the KiKK study that could explain this finding. The result, however, is in conflict with the assertion by radiation protection authorities that the estimated doses from nuclear power plants were at least a factor of 1000 too low to produce the observed effect.

A number of scientists have pointed out that official dose calculations often use inadequate propagation models and very low dose coefficients for internal emitters which, together, could account for a possible underestimation of doses by a factor 10 to 100. But we need to explain a difference of a factor of 1000.

A common assumption is that a 100% increase in effect requires a 100% increase in dose. This, however, is not true if the dose-response is non-linear. In addition, residents near Nuclear Power Plants are exposed to widely fluctuating dose rates over the year and not to a constant low dose rate. With a curvilinear dose-response, the effect will be determined not by the average dose but by the dose from emission peaks. This means close examination should be made of emission peaks, eg those resulting from the opening of reactors during refuelling.

To date, we do not know the shape of the dose-response curve for prenatal leukaemia induction. But after the Chernobyl accident, a significant increase of perinatal mortality was found in Germany and the risk depended on the dose to the power of 3.5, ie there was a curvilinear, not linear, dose-response relationship.

Biography: Dr Alfred KOERBLEIN

Studied physics at the University of Stuttgart (diploma 1972). followed by two years in North and South America (1973-1974). Undertook postgraduate studies in physics at the University of Heidelberg and at the high-flux research reactor (ILL) in Grenoble, France (1975-1978). Gained a PhD in Physics in 1978.


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Radiation Risks

Abstract

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Recent advances in our understanding of effects of radiation on living cells suggests that fundamentally different mechanisms are operating at low doses compared with high doses. Also, acute low doses appear to involve different response mechanisms compared with chronic low doses. Both genomic instability and so called “bystander effects” show many similarities with well known cellular responses to oxidative stress. These predominate following low dose exposures and are maximally expressed at doses as low as 5mGy. At the biological level this is not surprising. Chemical toxicity has been known for many years to show these patterns of dose response. Cell signaling and coordinated stress mechanisms appear to dominate acute low dose exposure to chemicals. Adaptation to chemical exposures is also well documented although mechanisms of adaptive responses are less clear. In the radiation field adaptive responses also become important when low doses are protracted or fractionated. Recent data from our group concerning bystander effects following multiple low dose exposures suggest that adaptive responses can be induced in cells which only receive signals from irradiated neighbours. We have determined using genetically distinct mice, with different radiosensitivities, that bystander effects occur in vivo and vary according to genetic background. We have data showing delayed and bystander effects in fish and in prawns following in vitro irradiation of haematopoietic tissue. These data have implications for environmental radiation protection of human and non-human species alike. Simple extrapolations from high to low dose exposure may need to be re-evaluated. This presentation discusses our knowledge about these low dose radiobiological effects in non-human biota and draws attention to the problem of defining the important questions relevant for the level of biological organisation being studied.

Speaker’s biography: Professor Carmel MOTHERSILL

Before 2003, Carmel ran the Radiation and Environmental Science Centre at the Dublin Institute of Technology, a centre which she founded and developed and she held the 17th Low Level Radiation and Health Conference in 2002. She moved to Canada when the centre had trained 30+ PhD students in radiobiology and was at the forefront of research in the low dose radiobiology field.

She went on to develop a new laboratory at McMaster University in Canada and now has a programme of research mainly centered around the implications of low dose effects of radiation in the environment. She continues to train graduate students and has developed new courses in radiation biology and radioecology. This includes the first ever on-site course at the Chernobyl Reactor where last year 24 students from all areas of science, social science and engineering were able to see the inside of the reactor and hear lectures from the Ukrainian and Belorussian scientists working there and in Gomel.

She and her team have been involved with important research findings which has led to changing the way people think about low dose radiation risk. While the discoveries were first greeted with outright disbelief, they are now accepted and most low dose radiation biologists are working on the mechanisms first identified by her team. These findings call into question the current Linear-Non-Threshold (LNT) models used in risk assessment and clearly demonstrate much more complex but exquisitely sensitive mechanisms, which evolved to deal with environmental changes.
Significant Contributions

- **1986 Discovery of radiation induced “Lethal Mutations**
  It is now realized that stochastic effects of radiation have a temporal dimension as well as being related to dose. From 1986 until present her team has characterized the response and shown that it predominates at low doses which means it has serious implications for risk modelling. Her current view is they can be harmful or protective and that the context of the macro- and micro-environment in which the radiation occurs determines outcome.

- **1997: Discovery of a medium transmissible radiation-induced bystander mechanism**
  Provided the first evidence that signals could be produced by irradiated cells which could induce “radiation-like” effects in never irradiated cells. Some previous evidence by other groups had suggested that radiation-induced information could pass between cells through gap junctions but not over long distances but her group showed in 1998 that gap junctions were not required.

- **2006: Discovered that fish can communicate radiation-induced bystander signals through water to other fish**

- **Discovery of a genetic basis for determining bystander radiation response**
  It was apparent before bystander effects were identified that genetic background played a role in determining outcome from radiation exposure

- **2007: Discovery of a role for serotonin in BE mechanisms**
  This discovery published first in 2007 arose from my realization that ionizing radiation could affect cell membranes in much the same way as a nerve impulse, i.e., by causing a transient depolarization of the membrane and that therefore neurochemicals which trigger cellular responses could perhaps mimic or be involved in mediating the bystander effect

Carmel has won a number of awards including an honorary DSc by Heriot Watt University (Scotland), the Timofeev-Ressovsky medal by the Russian Academy of Sciences and an outstanding leadership award by the International Dose Response Society and has been nominated for this year’s Bacq and Alexander Award by the European Radiation Research Society and for the Marie Curie Prize by the LowRad Society.

Carmel acts as a consultant to:
- the European Parliament on Genomic Instability from 1999 to now.
- the Marine Institute in Ireland concerning the establishment of a programme for Irish Marine Biotechnology 2003 to present.
- the Plaintiffs in the UK Atomic Veterans case 2008 to present.

and undertakes a range of public awareness activities:
- Advisor to numerous Non-Government Organisations (NGOs) in Canada and Europe concerned about in effects of low level radiation.
- Member of the European task group on the protection of the environment from ionizing radiation effects.
- Member of the EU task group on Public Perceptions in Biotechnology.
- Advisor and helper for the Low Level Radiation and Health NGO.

Peer-Reviewed Publications List 2004-2010 (Lifetime list 189 in PubMed)
Mothersill, C and Seymour CB, Ecosystems Radiobiology – From the Gene to the Stream, Mutation Research, Mutat Res. 2010 Jan 18. [Epub ahead of print]
Radiation biology of environmental and medical exposures

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The major adverse consequences of radiation exposures are attributed to DNA damage, arising as a consequence of deposition of energy in the cell nucleus at the time of exposure that has not been correctly restored by metabolic repair processes. However, the long-standing dogma that genetic lesions are restricted to directly irradiated cells (targeted effects) has been challenged by numerous observations in which effects of ionizing radiation arise in non-irradiated cells. These non-targeted effects are demonstrated in vitro in cells that are the descendants of irradiated cells (radiation-induced genomic instability) or in cells that have communicated with irradiated cells (radiation-induced bystander effects). Clastogenic factors capable of causing chromosome breaks in unirradiated cells can be detected in blood plasma after high dose exposures and there is a body of clinical and experimental radiotherapy data concerning, so called, abscopal or out of field effects where responses are detected in tissues or organs that are not irradiated. Taken together these various effects highlight additional mechanisms distinct from the conventional model of radiation-induced genotoxicity.

Because the responses of the haemopoietic system are major determinants of the health consequences of radiation exposure, experimental studies have been conducted to investigate responses of the bone marrow to various radiation exposures. Currently, the findings indicate that:

- Both targeted and non-targeted responses of bone marrow cells are influenced by genetic factors
- There are important differences between in vitro and in vivo responses and there may be a threshold for significant damage recognition and response in vivo
- Low doses of α-irradiation are effective in inducing non-targeted effects
- Environmentally-relevant low doses of X/g-rays do not induce significant non-targeted effects whereas higher doses, more associated with medical exposures, do produce such effects
- Delayed damage detected in vivo seems to be a consequence of an inflammatory mechanism produced in response to the effects of the initial irradiation and not due to direct signalling between irradiated and non-irradiated cells.

The emerging picture has implications for extrapolating in vitro findings to the in vivo situation, for mechanistic understanding of the response of the body to high-dose versus low-dose radiation exposures and then for understanding the development of associated pathologies.

Speaker’s biography: Professor Eric WRIGHT FRCPath FRSE

Eric Wright is Professor of Experimental Haematology in the University of Dundee Medical School. He is a graduate of the University of Sussex and obtained his PhD from the Faculty of Medicine in the University of Manchester. After research fellowships held at the Sloan Kettering Cancer Center in New York and the Paterson Institute for Cancer Research in Manchester, he was appointed Lecturer in Cellular Pathology at the University of St Andrews in 1980. In 1987 he moved to the Medical Research Council’s Radiobiology Unit at Harwell (subsequently re-titled the Radiation and Genome Stability Unit) where he held senior posts until 1999 when he moved to The University of Dundee.

From 2003-2008 he was Head of the Medical School’s Cancer Biology and Clinical Pathology Unit and from 2003 till earlier this year was Research Dean of the Medical School.

Prof Wright is a Fellow of the Royal College of Pathologists with a long-standing interest in the regulation of the haemopoietic system and the mechanisms underlying abnormalities of stem cell function, such as bone marrow failure and leukaemia development. He has had a particular interest in the cellular and molecular responses to radiation injury and in 1995 he presented the Alice Stewart lecture at the LLRH Conference. In 2007 he was elected a Fellow the Royal Society of Edinburgh having been awarded their The David Anderson-Berry Medal in 2004 for “his outstanding work on cellular, genetic and molecular aspects of radiation-induced
genomic instability in relation to the development of leukaemia and other diseases”. In 2007 he was awarded the Weiss Medal of the Association for Radiation Research, the Bacq-Alexander Award of the European Radiation Research Society and was elected a Fellow of the Higher Education Academy and of the British Institute of Radiology (BIR). In 2009 he was awarded the Silvanus Thompson Medal of the BIR.

In recent years he has served on numerous committees including the Committee on Medical Effects of Radiation in the Environment (COMARE), the Committee Examining Radiation Risks of Internal Emitters (CERRIE), the US Low Dose Radiation Research Program Committee and NASA’s Specialized Centers of Research Committee. He has been Chair of the Radiation and Cancer Biology Committee of The BIR, the Association for Radiation Research, the Scientific Advisory Committee of The Association for International Cancer Research and the Trustees of the LH Gray Memorial Trust. He has been a specialist examiner for the Royal College of Radiologists’ Faculty of Clinical Oncology, an Associate Editor of Radiation Research, a subject editor of the British Journal of Cancer and a member of the Editorial Board of Haematological Oncology.
Managing Radioactive Wastes  
One Hundred Plus Problems with Disposal

Dr Rachel Western BA (Oxon) PhD MRSC ¹

Introduction

In a nuclear reactor neutrons pound atoms and as a result radioactive atoms are formed. These are unstable and naturally transform in order to become stable. In the process they release particles and energy. Critically the particles and energy released are able to damage DNA

DNA² is the ‘blue-print’ for life and once DNA becomes damaged it can cause cancer or birth defects.

Damage to DNA caused by just one radioactive atom would be sufficient to cause cancer. Thus, the Health Protection Agency (HPA) state:

“a single radiation track … has a finite probability, albeit very low, of generating the specific damage to DNA that results in a tumour initiating mutation.”³

This statement does not mean that every individual radioactive atom that hits the body will cause cancer. It is saying that there is the potential.

‘Lethality’ of Waste Nuclear Fuel

In a nuclear reactor huge quantities of radioactive atoms are created – to the extent that the waste fuel rod that is taken out of the reactor is so lethal that it would almost immediately kill someone if they were to be anywhere near it⁴.

The nuclear industry relies on ‘shielding’ in order to stop the wastes killing people in such a direct way. However some of the wastes will still exist one million years into the future and even though the wastes would be much less intensely radioactive after that time, people would still need to be protected from it.

Burial – the Knee Jerk solution to the RadWaste Problem

The significance of the RadWaste problem was first officially recognised in the mid 1970s in the so-called ‘Flowers Report’⁵ and the immediate knee-jerk reaction was that all that was needed was a burial site⁶.

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¹ Nuclear Researcher for Friends of the Earth (Cumbria Groups) and Member of Nuclear Waste Advisory Associates (NWAA)
² deoxyribonucleic acid
⁴ See: Allan Hedin “Spent nuclear fuel – how dangerous is it? A report from the project “Description of risk’.” SKB Report - Technical Report TR-97-13 (March 1997). See Figures 3-8a and b (See pp 22- 23) and para 3.5.2 - (page 21)
However, over 30 years later it is clear that the wishful thinking that led people to believe that wastes could simply be cemented up deep underground – and that they would stay put – is simply not born out by a technical analysis of the processes that would be likely to take place.

The most important point to recognise is that despite the nuclear industry’s description of the magnitude of the problem in terms of the volume of the wastes, the heart of the matter lies in the quantity of radioactive atoms (radionuclides) – and in particular their chemical behaviour under the burial conditions.

**The Radioactive Cauldron**

Key to the nuclear industry’s notion of the potential of burial as a means of ensuring long term protection from radionuclides is the idea that to all intents and purposes they would be held underground for hundreds of thousands of years into the future. This means that the possibility that they would chemically react to change into a mobile form – such as liquid or gas needs to be largely discounted.

However, the basis for this assumption rests on the idea that it is somehow possible to make predictions of radionuclide behaviour based simply on the chemical element concerned. For example for the isotope carbon-14, the nuclear industry base their calculations on an attempt to predict the behaviour of ‘carbon’ in the burial facility.

The absurdity of this approach can be appreciated by doing a simple thought experiment comparing the solubility of a diamond ring which contains a crystal of pure carbon, with the solubility of sugar, which contains crystals of carbon together with water (‘carbo-hydrate’).

Obviously diamonds do not dissolve – even over thousands of years – whilst sugar in hot tea or coffee will dissolve in its entirely almost immediately. Thus using data for these two forms of carbon to provide a figure for the ‘solubility of carbon’ would give a figure of somewhere between zero and infinity. Similarly, error ranges of 100 million can be cited for uranium$^7, 8$.

Clearly data spanning this range is essentially useless. for the task of predicting the degree of transference of radionuclides from a deep burial facility back to the surface. However it is indicative of the ‘wrong-headedness’ of the mechanical engineers, nuclear physicists and mathematicians who dominate the ‘conceptual framing’ of the risk prediction calculations that are used to argue that RadWaste burial would not result in dangerous leakage.

**Technical Scrutiny of Burial**

In the 1990s the UK nuclear waste agency ‘Nirex’ planned to begin excavation work at the site of their proposed burial facility near Sellafield in Cumbria. The project was subject to detailed technical scrutiny at a Public Inquiry. The conclusion reached by the Inquiry Inspector was that the nuclear industry should not be given the go-ahead to begin their planned programme “in [their] current state of inadequate knowledge”$^9$. As a result the project was shelved.

In March 2010 the Nuclear Waste Advisory Associates (NWAA) compiled a register of current technical issues that remain to be resolved if a technical case for radioactive waste disposal is to be made. Over one hundred

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$^8$ D Swan and C P Jackson (SERCO) ‘Formal Structured Data Elicitation of Uranium Solubility in the Near Field - Report to Nirex’ (SA/ENV/0920 Issue 3 - March 2007 – page 6 – provides a more recent reference

issues were identified in areas including: inventory, gases, site considerations, construction, waste package and repository components, chemistry and contamination levels, plutonium and uranium-235 (nuclear energy issues), living things and microbes, limitations of further research, timescales and methodology for risk prediction.

In the remainder of this paper the range of the technical problems that undermine the notion of disposal will be considered – and finally the context of the disposal debate - lying as it does in the midst of a political imperative to provide a smooth path for New Build will be addressed.

**Inventory**

An idea of the problems with the official nuclear waste inventory is that the information is graded according to both the ‘uncertainty’ of the data and also its ‘reliability’\(^\text{10}\). The possible adoption of new reactor types or changes in fuel design – which has been proposed for New Build reactors - would necessitate further research. For example, higher burn-up and MOX\(^\text{12}\) fuel would require new waste container design and more research on how such containers would behave on disposal\(^\text{13}\). Considerations include higher temperature and higher risks of brittleness due to increased exposure to radioactivity\(^\text{14}\).

**Gases**

It has been realised for some time (since at least 1987)\(^\text{15}\) that a disposal facility would be likely to produce a large quantity of hydrogen gas\(^\text{16}\). Although this gas would not be radioactive, it would present a problem due to the large volumes involved and the resultant need to provide a release pathway in order to avoid a build up of pressure.\(^\text{17}\) Such a release pathway would necessarily also provide an escape route for radionuclides. The provision of such an ‘escape route’ is contrary to the notion of a disposal facility as a sequence of ‘barriers’\(^\text{18}\).

Despite the fact that the hydrogen problem has been recognised for over twenty years, it is still not clear whether a hydrogen ‘over-pressure’ would lead to the opening of fractures and the resultant creation of fast ‘migration pathways’\(^\text{19}\).

**Radioactive Carbon – High Doses within Short Timescale**

Radioactive waste stocks contain a large amount of ‘carbon-14’ which is radioactive. The nuclear industry had predicted that, following disposal, this carbon would be held underground due to a so-called ‘carbonation’\(^\text{10}\)

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\(^{10}\) [http://www.nuclearwasteadvisory.co.uk/uploads/6901NWAA%20ISSUES%20REGISTER%20COMMENTARY%20letterhead.doc](http://www.nuclearwasteadvisory.co.uk/uploads/6901NWAA%20ISSUES%20REGISTER%20COMMENTARY%20letterhead.doc)

\(^{11}\) the ‘reliability’ relates to whether the data was measured or estimated

\(^{12}\) ‘MOX’ – stands for ‘mixed oxide’ fuel – which contains plutonium as well as uranium


\(^{14}\) EU JRC (Oct ’09) page 12


\(^{16}\) The gas would be produced due to the corrosion of iron within an atmosphere that doesn’t contain oxygen. The steel would be used both for waste containers and also in structural components of the disposal facility.


\(^{18}\) EU JRC (Oct ’09) page 10

\(^{19}\) EU JRC (Oct ’09) page 20
reaction with repository cement. However in November 2005, the Environment Agency queried the extent to which such a reaction would take place.

More recently, the nuclear industry has acknowledged that this radioactive carbon could instead react with hydrogen and form methane gas (\(\text{CH}_4\)). Due to its carbon-14 content, this methane would be radioactive. The presence of the carbon-14 as a gas rather than as a ‘cement/carbon’ chemical compound would make it much more likely to escape from the disposal facility. Thus, the nuclear industry has calculated that the escape of radioactive methane would result in a dose four thousand times greater than the dose considered ‘tolerable’ by the EA.

Furthermore, it has been calculated that this dose could arise just forty years after the proposed disposal facility was closed.

**Site Considerations**

The gas issue presents a double dilemma for repository site selection. The traditional notion of an ideal disposal site is one that presents a ‘barrier’ to radionuclide release. However, as discussed above, such a barrier would also prevent hydrogen release. This would result in a pressure build-up and must therefore be avoided. On the other hand, allowing the escape of hydrogen gas would also allow the escape of radioactive methane gas, which – as stated above – has been predicted to give rise to a very high dose on a very short timescale.

However, the geological screening criteria set out on pages 74 –75 of the DEFRA White Paper “A Framework for Implementing Geological Disposal” (June 2008), do not indicate any sign of cognisance of this issue.

Further site problems arise due to the simple fact that ascertaining the underground flow regime is not at all straightforward. For example high permeability features may dominate water flow; however it is difficult to establish the frequency, spread and distribution of such features and the interconnection of high-flow features over a regional scale “cannot be known with certainty”.

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20. EA (Nov 2005) Environment Agency Comments on Nirex ‘Viability’ Report’, (Nov ’05). *a key assumption is that all C-14 labelled carbon dioxide does not escape from the repository, but reacts with backfill via a carbonation reaction. In our view, more confidence is needed that complete reaction of carbon dioxide will occur in cracked backfill or that the gas pathway would not lead to unacceptable consequences were this not to be the case.* (see pp 10-11)


22. Sources:

- Nirex (Feb ’06) page 1 – Tolerable Carbon dose = 2.4 x 10^-3 units. (i.e TBq/year); NDA (Mar ’08) page 75 – Predicted Carbon Dose = 10 units. (TBq/year); [10 / 0.0024 = 4,000 times]; Nirex (Feb ’06) page 12 (Fig 1) – peak dose shown at 40 years post-closure;
- Nirex, (Feb ’06) “C-14: How we are addressing the issues” (Technical Note: Number: 498808); NDA: (Mar ‘ 08) ‘PAMINA Gas Report’ “Uncertainties Associated with Modelling the Consequences of Gas” Deliverable (D-N°: D2.2.B.2); Simon Norris (NDA) Nuclear Decommissioning Authority. 26th March 2008.
- eu.jrc (Oct ’09) page 10
- eu.jrc (Oct ’09) page 15
- eu.jrc (Oct ’09) page 10
- eu.jrc (Oct ’09) page 15
- eu.jrc (Oct ’09) page 10
- eu.jrc (Oct ’09) page 15
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- eu.jrc (Oct ’09) page 15
- eu.jrc (Oct ’09) page 10
**Constructability issues**

It is becoming apparent that it may be necessary to compromise between measures needed to stabilise an excavation and the detriment caused to the safety case by the introduction of foreign material\(^{29}\). In addition the volume of rock around the excavation that is damaged is expected to result in flow pathways\(^ {30}\). Moreover a disposal facility would be a disturbance to the natural mechanical/flow/heat/and chemical processes at the site\(^ {31}\). It is recognised that these processes would act to dissipate the disturbance but their interactions are not understood and require further investigation\(^ {32}\).

**Worker Doses**

In their (January 2010) Disposability Assessment\(^ {33}\), the NDA reported that it was unwilling to “*make any claim for the acceptability of (Operational) doses*”\(^ {34}\), stating, instead, that the estimates of worker dose were intended to “*provide insight into the key issues*”\(^ {35}\). This indicates that, according to present estimates, worker doses would be unacceptable.

**The Waste Package Itself**

In October 2009, CoRWM\(^ {36}\) expressed concern over the level of R&D effort being devoted to determining the lifetimes of Intermediate Level Waste Streams\(^ {37}\). CoRWM commented that, given the potential significance of waste form performance for ‘disposability’, the effort being devoted to resolving uncertainties over product lifetimes did not seem to be sufficient.\(^ {38}\) The influence of different possible waste forms on the design choices for the repository components is a ‘*major knowledge limitation*’\(^ {39}\).

An indication of the problem may be given by the fact that 17,000 waste packages have been incorrectly conditioned using cement as the matrix and are due to fracture within 150 years due to an ‘*expansive*’ chemical reaction\(^ {40}\).

Research is also being carried out on both the mechanisms and the probabilities of canister failure\(^ {41}\). There are particular concerns in respect of copper. The NDA refers to a copper canister wall thickness of 5 cm as a

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\(^{29}\) EU JRC (Oct ’09) page 14
\(^{30}\) due to the opening of fractures – caused by stress release
\(^{31}\) EU JRC (Oct ’09) page 20
\(^{32}\) EU JRC (Oct ’09) pp 20-21
\(^{34}\) page 91
\(^{35}\) page 91
\(^{36}\) CoRWM – the Committee on Radioactive Waste Management
\(^{37}\) ILW – intermediate level waste
\(^{40}\) EA (Aug ’09) page 141
http://environment-agency.resultspage.com/search?q=R&amp;srid=S8%2d2&amp;lbc=environment%2dagency&amp;w=longevity&amp;url=http%3a%2f%2fwww%2environmcnt%2dagency%2dgov%2deuk%2dstatic%2ddocuments%2dBusiness%2dfe%2dpdf&amp;rk=4&amp;uid=802543385&amp;sid=15&amp;ts=ev2&amp;rsc=ljCMVqGgQAWT95Na&amp;method=and&amp;isort=score
\(^{42}\) EU JRC (Oct ’09) page 12
means of securing long-term durability. However, according to research published (July 2009), a copper wall thickness of one metre would be required for long-term (100,000 year) durability. It is not clear how such a wall thickness would be either logistically or economically achievable.

**High Level Wastes**

The interaction of waste fuel with other repository components needs to be investigated. Furthermore, the interactions between the glass matrix of vitrified high level waste (HLW) and ‘clay-type’ materials planned for repository use is also difficult to predict.

HLW would be very hot and as such would affect the behaviour of the clay-based materials planned for repository use as a backfill. Specifically, the chemical, mechanical and flow behaviour of the clay would be affected. The heat from the wastes would dry out the clay and alter its ‘suction potential’. The EU is presently setting up a new work area on these issues.

**Examples of Chemical Effects**

In 1989, the International Atomic Energy Agency (IAEA) identified a specific problem relating to the increase in the solubility of radionuclides caused by organic breakdown products that was sufficient to increase doses above the regulatory limit. A likely source was thought to be decomposition products of ‘cellulose’, the woody compound used to make paper. Cellulose break-down products have been observed to increase radionuclide solubility by up to 10,000 fold, with plutonium being a particular problem.

Another chemical consideration that points to the extreme difficulties associated with attempting to predict the degree of leakage from a nuclear waste dump is provided by the attempts to quantify ‘sorption’. Sorption is the process of radionuclide take-up by solid surfaces. It has been studied for many decades. However, the ‘batch’ technique which has largely been used relies on crushed samples to obtain data values. This

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42 NDA - “Geological Disposal - Generic Design Assessment: of Disposability Assessment for Wastes and Spent Fuel arising from Operation of the UK EPR” NDA Technical Note no. 11261814 – Summary See - Figure B7 - Illustration of an EPR spent fuel disposal canister “ (page 27)

43 EU JRC (Oct '09) page 11

44 EU JRC (Oct ’09) pp 11-12

45 EU JRC (Oct ’09) page 13

46 EU JRC (Oct ’09) page 13

47 EU JRC (Oct ’09) page 13

48 EU JRC (Oct ’09) page 13


52 Cross (1989) NSS/R151p3 Op cit

53 EU JRC / Oct ’09 page 18

54 as compared to solid ‘block samples’ which are used in the ‘through-diffusion’ measurement technique

technique is very far removed from the actual uptake mechanisms that would be relevant\textsuperscript{55}. Nevertheless, despite the recognition that the measured values “\textit{do not have any predictive capabilities}”,\textsuperscript{56} they are still widely used in risk estimates\textsuperscript{57}. Equations are available that would more closely represent reality but these are not used due to the lack of data and also the computer capacity that would be required\textsuperscript{58}.

**Possible Impact of Nuclear Energy Chain Reaction**

Nuclear wastes contain plutonium and uranium-235, which are able to initiate a nuclear energy chain reaction (or ‘\textit{criticality}’). Both the probability and impact of such an event are not known.\textsuperscript{59} The UK nuclear industry has built up 100 tonnes of separated plutonium, which is not currently incorporated into the repository risk estimate.\textsuperscript{60} Long-term management of this plutonium will need to be considered at some stage, either in the separated form or as ‘waste MOX’\textsuperscript{61} or in some other form.

**The Nuclear Weapon Dilemma**

Quite apart from the fact that plutonium and uranium-235 are the raw materials for ‘State’ nuclear weapons, it would also be possible to make a ‘dirty bomb’ out of more general radioactive wastes. This introduces an additional dilemma into long-term waste management.\textsuperscript{62} On the one hand, these potential bomb materials should be put out of reach; on the other hand, they should be kept at hand in order to be sure that they have not somehow been accessed by potential bomb makers.

**Living Things and Microbes**

In addition to all of the problems cited above better understanding of the long-term implications of the impact of radionuclides on living things\textsuperscript{63} is required. The potential importance of microbes, which can be found deep underground\textsuperscript{64}, has long been underrated\textsuperscript{65}. This is of concern as microbes may well be the determinant factor in the outcome of a reactive chemical system\textsuperscript{66}. The role of microbes in proposed disposal systems is not fully understood\textsuperscript{67} yet despite this, only a few laboratories are undertaking research on microbe/radionuclide interactions\textsuperscript{68}.

**Further Research will not necessarily provide desired outcomes**

It is intrinsic to scientific method that the outcome of a research programme cannot be predicted – otherwise there would be no need to carry out the research. This means that simply allocating time and money to the issues that challenge the disposal programme will not guarantee that the issues will be resolved. Thus the

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\textsuperscript{55} EU JRC (Oct ‘09) page 18  
\textsuperscript{56} EU JRC (Oct ‘09) page 18  
\textsuperscript{57} EU JRC (Oct ‘09) page 18  
\textsuperscript{58} EU JRC (Oct ‘09) page 18  
\textsuperscript{59} EA (Jan ‘10) page 16  
\textsuperscript{60} EA (Jan ‘10) page 16  
\textsuperscript{61} ‘MOX’ – refers to fuel rods that contain both plutonium oxide and uranium oxide.  
\textsuperscript{62} See also the ‘gas dilemma’ considered above  
\textsuperscript{63} NEA \textit{Contribution to the Evolution of the International System of Radiological Protection} (2009)  
\textsuperscript{64} EU JRC (Oct ‘09) page 20  
\textsuperscript{65} EU JRC (Oct ‘09) page 19  
\textsuperscript{66} EU JRC (Oct ‘09) page 20  
\textsuperscript{67} Strand et al (2004) page 20  
\textsuperscript{68} EU JRC (Oct ‘09) page 20
Environment Agency has pointed out that it is possible that the results of disposal research programmes may not actually indicate that disposal would be safe.\(^6\)

**Conclusion**

Despite the fact that in October 2009 the Committee on Radioactive Waste Management (CoRWM) published a research report setting nearly 30 pages of technical research issues;\(^7\) in their ‘statement of position on new build wastes’\(^8\) they state that their role is to provide advice on the:

> “maintenance of public confidence in plans for the long-term management of new build wastes, in addition to existing and committed wastes” (page 3)

Despite the fact that CoRWM’s own conclusions on RadWaste research indicate that such ‘confidence’ would be misplaced – they are caught up in the New Build vortex which insists on a Public Relations led approach.

The UK faces a horrendous nuclear waste problem for which no clear resolution is in sight. Far from exacerbating this crisis through adding on new wastes from New Build it is essential that the industry, the regulators and the Government treat the issue with the care and humility that it deserves.

**Speaker’s biography: Dr Rachel WESTERN BA (Oxon) PhD MRSC**

Rachel’s first degree was in Pure Chemistry followed by a PhD that examined the documentation put forward by the nuclear industry in the context of nuclear decision making. From 1990 to 2004 she was Nuclear Researcher for Friends of the Earth (HQ). The most important project that she worked on during this time was her work as Research Coordinator for the ‘Nirex’ Planning Inquiry.

This Inquiry looked at whether ‘Nirex’ (the Nuclear Waste Management Executive) should be given permission to begin excavation works at their planned nuclear waste facility. The Inquiry concluded that the Nuclear Industry's case was technically inadequate.

From 2001 to 2006 Rachel worked as a Consultant to Nirex working on Sustainability and Transparency issues. Recently she has been working as part of ‘Nuclear Waste Advisory Associates’ (NWAA) and also as Nuclear Researcher for the Cumbrian Friends of the Earth groups.

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\(^{8}\) [http://www.corwm.org.uk/Pages/e%20Bulletins/2749%20Final%20CoRWM%20Statement%20new%20build%20wastes%202%20March%202010.pdf](http://www.corwm.org.uk/Pages/e%20Bulletins/2749%20Final%20CoRWM%20Statement%20new%20build%20wastes%202%20March%202010.pdf)
UK Uranium supplies: health and environmental impacts

Peter Diehl WISE Uranium information website

Uranium is imported to Britain from Australia and Namibia. In both of these countries, uranium is mined in very remote areas, even in National Parks. In South Australia and Namibia, the ore grades of the deposits mined are extremely low, requiring the mining and processing of vast amounts of material to get at the uranium, and leaving behind large amounts of uranium mill tailings that have to be managed safely for hundreds of thousands of years. Water is a scarce resource at many of the sites and has to be supplied at high environmental cost. All of the sites have experienced a long list of spills and other incidents, endangering groundwater and surface waters.

Although legacies from old uranium mines still have not been cleaned up appropriately, new projects are being planned at many sites. Moreover, in Namibia, several projects are beginning to process ores of extremely low ore grades (three times lower than mined so far), requiring much larger devastation of landscape and environment. The Namibian government nevertheless takes every effort to accelerate these projects and approves them at breathtaking speed, leaving no room for a thorough assessment of their environmental impacts.

Speaker’s biography: Peter DIEHL

Peter has been involved in uranium mining issues since 1982, when he joined a local environmental group opposing the development of a new uranium mine in the South western part of Germany. In the late 1980s and early 1990s he was busy networking among environmental groups concerned about uranium mining all over Europe. Since 1995, he has been running the Uranium Project of the World Information Service on Energy (WISE), an Amsterdam-based NGO providing networking services for anti-nuclear groups worldwide.
The Hugh Richards Workshops

Hugh Richards was an architect who set up the Welsh Anti Nuclear Alliance and campaigned fervently for a non-nuclear future. Hugh died in August 2010 and the Workshops which form a key part of the Low Level Radiation and Health Conference are now named in his honour.

Hugh managed to sustain a prodigious contribution to the anti-nuclear movement which he generously shared widely, and an analysis which has proved invaluable. His work on:
- repository footprint,
- spent fuel management and
- high burn up fuel

was based on careful research and thoughtful analysis. It demonstrated that the nuclear industry’s plans for long-term management of new build wastes are quite literally unsustainable. Hugh’s work was seminal and will continue to play a major part in undermining the scientific and ethical basis for any expansion of the nuclear industry.

His work was much appreciated by all those of us campaigning against the further development of the nuclear industry and its plans for nuclear waste management. We intend to ensure that its influence on the debate continues undiminished even when you are unable to continue your work. Your legacy may well have a long half-life.

Many campaigners came to know and appreciate Hugh, not only as a doughty and indefatigable campaigner but as a person - for his humour, guts and, above all, his humanity.

These workshops are named in honour of Hugh as an appropriate way of both marking his efforts and continuing his legacy. But, in other ways, too, inspired by his example, we intend to carry the fight to a successful conclusion. We know this is your greatest wish.

Hugh, thank you for everything you have done to help make the world a better place. It has been truly a pleasure and a privilege to know you.

Workshops:

Forgotten Heroes? A Case Study of Britain’s Cold War Atomic Test Veterans, and the Burden of Proof.
Dr Tracey Morris

This paper is built on, and brought up to date, from a previous MA dissertation written at the University of Kent at Canterbury in 2004 entitled: The Politics of Truth: Justice and Reparations for British Veterans of Britain’s Cold War Nuclear Testing Programme.

During the Cold War Britain was involved in an arms race to develop atomic weapons. Over 40,000 Commonwealth service and civilian personnel took part in Britain’s atomic testing programme. The United Kingdom supplied over 20,000 test participants: many were National Service men, and many participants witnessed multiple detonations.

In 1983, with the founding of the British Nuclear Test Veterans Association and a 1984 Royal Commission ordered by the Australian Government, many British veterans have publicly campaigned for reparations from the British Government with the conviction that their illnesses, and those of their descendants, are attributable to their participation in Britain’s nuclear test weapons’ programme. The principal aim of the paper is to highlight whether the British Government has done all it can to allay the fears of the veterans, and to acknowledge the sacrifice the servicemen made to ensure Britain’s nuclear testing programme was a success. Whilst looking at the standards of the day this paper will provide a brief synopsis as to why Britain needed its testing programme and how it was carried out. It will look into how the veterans were constrained by litigation, thus promoting decades of silence. The paper will draw attention to some of the studies carried out by the British Government and the veterans to highlight any conflicting evidence. Finally, the paper will bring up to date the veterans’ continued campaign for reparations, and the continuing burden of proof.
Workshop session report:

Tracey spoke to her presentation and her information was supplemented by contributions from:

Ken McGinley and colleague who set up the British Nuclear Test Veterans Association in 1983; Katherine Trundell who is researching the New Zealand test veterans; and Dr Chris Busby who has been supporting the Test Veterans in their Court case. The current situation is reflected in the following reports from the Guardian newspaper and from a debate in parliament. See below:

Nuclear test veterans win right to sue MoD

1,000 servicemen exposed to radiation in South Pacific and Australia during 1950s claim for cancer and other illnesses

The Guardian, June 5th 2009

Military veterans who claim they were negligently exposed to excessive radiation during nuclear tests in the 1950s won a high court case today permitting them to sue the Ministry of Defence, exposing the government to a potential compensation bill running into hundreds of millions of pounds. A group of around 1,000 veterans of tests in the South Pacific and Australia between 1952 and 1958 launched the case as they believe radiation exposure caused illnesses including cancer and chromosome damage.

The MoD argued that the group had waited too long to lodge its claim and was thus excluded under limitations regulations. It also argued that the cases were certain to fail at any eventual trial.

But giving his verdict in the high court in London today, Mr Justice Foskett rejected these arguments, pointing to a recent scientific study involving veterans in New Zealand which provided new evidence of the potential health impact of the tests, which would be "crucial and pivotal" for any potential case against the MoD.

Five of the 10 lead cases he had considered were allowed to proceed as well on grounds of fairness, the judge said, delivering a 217-page judgment. The judge urged ministers to consider a settlement rather than drag out legal proceedings further.

The judgment was witnessed by dozens of veterans and their relatives, who immediately decamped to the front steps of the high court building in central London to celebrate, cheering and spraying champagne.

"I'm absolutely over the moon," said Don James, who was deployed on Christmas island, a remote Pacific atoll also known as Kiritimati, during five offshore nuclear tests in 1958. "We had no special kit. They just told us to turn your back to the blast and cover your eyes. You could see the bones in your fingers," he said. "I have a blood disorder now, and so does my daughter. I'm still very angry. It should not have come to this. If they had owned up at the beginning they could have released documents and let us understand what happened."

Neil Sampson from Rosenblatt, the firm of solicitors which led the case, said he was "appalled, if not disgusted" with the way the government had allowed the issue of compensation to drag on, and the way the MoD fought the case.

"Prime minister after prime minister over the past 50 years have said that if veterans could prove that they had been exposed to radiation they would be compensated," he said. "When we could prove that they had been exposed to radiation the MoD says, 'Sorry guys, you're too late.' That's disingenuous. It's not right. It's appalling." He accused ministers of wanting to delay the case so long that all the claimants would be dead: "There is no other conclusion that one could reach."

With 59 of the veterans involved having died since the action began, Sampson said, he was hopeful the MoD would now reach a settlement with the surviving veterans, a process which would take a matter of months. A full trial would take three years even to prepare, he estimated.

In total, around 25,000 forces members from the UK, Australia and New Zealand were stationed near nuclear blasts, the first of which took place on the Monte Bello islands off north-west Australia in 1952. Subsequent tests were at Maralinga, a desert
region of mainland South Australia, and Christmas island.

While New Zealand, along with the US, France and Canada, has previously paid money to service personnel involved in nuclear tests, the MoD has always insisted that there is no evidence its troops were exposed to excessive radiation.

Hansard

**Nuclear test veterans won right to sue MoD**

1,000 servicemen exposed to radiation in South Pacific and Australia during 1950s claim for cancer and other illnesses

*The Guardian*, June 5th 2009

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Five of the 10 lead cases he had considered were thus permitted, while the other five should be allowed to proceed as well on grounds of fairness, the judge said, delivering a 217-page judgment. The judge urged ministers to consider a settlement rather than drag out legal proceedings further.

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While New Zealand, along with the US, France and Canada, has previously paid money to service personnel involved in nuclear tests, the MoD has always insisted that there is no evidence its troops were exposed to excessive radiation.

**Speaker's biography: Tracey MORRIS**

Tracey is a PhD candidate in International Relations at St Andrews University. As a historian her current research revolves around the British Empire’s Cold War nuclear testing programme 1940 – 1958. In 2004, she completed an MA thesis: The Politics of Truth: Justice and
Reparations for British Veterans of Britain’s Cold War Nuclear Testing Programme at the University of Kent at Canterbury which involved a case study of Operation Hurricane and the campaign for legal justice. She is currently working as an Associate Teacher for the Politics and International Relations Department at the University of Leicester.

Health effects at very low levels of radiation
John Urquhart, PhD student, Open University

This workshop examines the limitations of the current radiation paradigm of health effects from low-level radiation. It draws attention to unexpected increases in child cancer in England and Wales associated with the Chernobyl nuclear accident. The excess relative risk per Sievert is calculated from exposure to three different sources: Chernobyl fallout, and French and German nuclear power stations. These give similar results of $5 \times 10^4$ per Sievert, some 10,000 times that used in the existing radiation paradigm. The reasons for this discrepancy are examined, including the inadequate statistical methods used by COMARE. The workshop includes hands-on experience in composing an urgent memo at ministerial level to cope with expected fallout within the next four days from a nuclear accident. This will take into account the latest biological and genetic hypotheses, and employ the precautionary principle.

Workshop report by Tom Chadwick
Workshop chaired by Dr Helen Wallace, Genewatch

This presentation questioned the limitations of the current paradigm of health effects from low-level radiation. These limitations were expressed as being mainly based on Japanese A-bomb survivors, no data before 1950, no fallout effect recorded, no measurement of internal dose, and the duration of exposure not considered.

Details of unexpected increases in child cancer in England and Wales over the period 1971-1992 and associated with the Chernobyl accident were explained. The evidence took account of one or more of the following periods of exposure: prompt cancer response, in utero exposure, pre-conception paternal irradiation and pre-conceptional maternal irradiation. This was compared with exposure from German and French nuclear power stations, with particular reference to the KiKK study. This gave rise to a result which suggests that exposure could be in the order of 10,000 times that used in the existing paradigm.

The second part of the presentation was to have been a challenge to the audience to act as advisor to the government on a fictional nuclear accident. Using the latest biological and genetic hypotheses and the precautionary principle the workshop audience were asked to prepare an urgent memo to the appropriate minister. However, when some of the issues raised were challenged and required a detailed reply the second part was, by consensus, replaced with a detailed question and answer session. This ran out of time and the following addendum is a fuller response to the questions raised.

*****

Email correspondence from John Urquhart to Dr Alfred Koerblein of the Munich Environment institute who attended the conferences in 2006 and 2008 and gave a presentation at the Silver Anniversary event.

As you know from my workshop, I was very interested in the fact that the total doses around nuclear power plants, both in France and Germany were probably similar to those experienced in Britain from Chernobyl fallout. My main conclusion was that the figures for extra leukaemias in England and Wales could be construed as the same order of magnitude as those for the KiKK study, i.e. ERR ≈ 50,000 per Sievert, which appears to be up to 10,000 times greater than that predicted by the existing radiation paradigm. However, in both my Chernobyl study, and the KiKK study, we are dealing with children under the age of five, and what happened to them after the Japanese A-bombs would not have been observed at Hiroshima or Nagasaki simply because the surveys did not start until October 1950. In any case, the chaotic post-war conditions in Japan would probably have meant that many leukaemia cases died from infection and were not noted.
Thus, when it is suggested that it is difficult to believe that the current radiation paradigm could be out by more than a factor of ten, the absence of Japanese data before October 1950 should be taken into account.

As I observed in the workshop, there is no evidence in the KiKK study of any increases in leukaemia incidence after the age of five, whereas Stewart's seminal work on the effects of in utero exposure definitely shows increases up to the age of twelve (Mole 1990). My Chernobyl study did not find an increase beyond the age of three. It does not follow, as Eric Wright pointed out, that there is no in utero effect in either study - in fact, in a previous study which I presented to the LLRH conference in Canada in 2006, I found an increase in neonatal deaths in those parts of England and Wales which had increased levels of Chernobyl fallout.

Your question about why not use regression techniques to examine the very significant increase in under-three solid tumours in 1987 opens up a whole philosophical can of worms. Conventionally, statisticians have assumed that time series are a valid approach to comprehending fluctuations in data. But, all time series analysis may violate what I consider to be the first principle of science, namely that future events have less influence on the past than past events have on the future. Yet, all time series which produces an explanatory curve, do so by giving equal weight to events after a particular time as to those before a particular time, which seems to me illogical. When discontinuities occur in any run of events, particularly when they are multiple, then the conventional time series approach may obscure important conclusions. I think this is particularly true of the under-three leukaemia data, which showed two unexplained increases, and then a later general increase, and incidentally a decrease in n1975/6, which I did not have time to explain in detail.

I think that the pronounced increase in childhood leukaemia in the KiKK study in the 0-5km zone compared with the 5-10 zone suggests a multifactorial source, both genetic and environmental. It is interesting to note that Gardner's discovery of increased childhood leukaemia in the offspring of male Sellafield radiation workers did not extend to children of workers living outside the Seascale area, which suggests a possible combination of genetic and environmental triggers.

Speaker’s Biography: John URQUHART

After obtaining an honours degrees in mathematics and statistics at Leeds University, John spent the next six years in post-graduate research on novel statistical applications, first as a scientific officer in the scientific civil service in the Marine Laboratory Aberdeen, and then as a statistical consultant to the Library Management Research Unit at Cambridge University. He then became Head of Acquisitions at Newcastle University Library, but continued his interests in statistics and the environment. In 1983, he was the statistical consultant to the YTV film Windscale, the Nuclear Laundry which discovered a ten-fold excess of childhood leukaemia near the Sellafield (Windscale) nuclear reprocessing plant in Cumbria, north-west England. After that, he was consultant for several television documentaries, including Children of the Bomb, a Tyne-Tees Television programme which demonstrated an increase in birth defects in children of British army veterans exposed to nuclear tests. In 2002, he started work on the possible health and genetic effects of the Chernobyl nuclear accident, and has been studying for a PhD in genetics at the OU.
A Chronology of Health Problems Related to Three Mile Island
Submitted by webEditor on Sun, 02/01/2009 - 20:43

The record indicates that in reporting to state and federal officials on March 28, 1979, TMI managers did not communicate information in their possession that they understood to be related to the severity of the situation. The lack of such information prevented state and federal officials from accurately assessing the condition of the plant.

In addition, the record indicates that TMI managers presented state and federal officials misleading statements—statements that were inaccurate and incomplete, that conveyed the impression the accident was substantially less severe and the situation more under control than what the managers themselves believed and what was, in case, the fact. (“Reporting of Information Concerning The Accident At Three Mile Island,” A Report Prepared by the Majority Staff of the Committee On Interior and Insular Affairs of the U.S. House of Representatives, 97th Congress, First session, March 1981.)

For 11 days, in June and July 1980, MetEd illegally vented 43,000 curies of radioactive Krypton-85 (beta and gamma, with a 10-year half life) and other radioactive gasses into the environment without having scrubbers in place (6).

In November 1980, the United States Court of Appeals for the District of Columbia ruled that the krypton venting (June-July, 1980) was illegal. In February 1981, a $20 million fund was set up to pay over 15,000 claims for affected area residents and business within the 25-mile radius of TMI. Another $5 million was set up to establish the TMI Public Health Fund. However, several years after the establishment of the TMI Public Health Fund (1986), TMI-Alert and area political representatives unsuccessfully petitioned the federal court to remove the Fund’s administrators due to nepotism and poor communication with the community. The lead attorney in the class action, David Berger of Philadelphia, received $1,389,06 ($25-$260 per hour); his family law firm billed $175,056 and an additional $20,112 for report preparation. Legal bills totalled $2.5 million, which was less than the $4 million the attorney requested from the Court. Judge Sylvia Rambo received the fees.

March, 1982: The American Journal of Public Health reported: “During the first two quarters of 1978, the neonatal mortality rate within a 10-mile radius of Three Mile Island was 8.6 and 7.6 per 1,000 live births, respectively. During the first quarter of 1979, following the startup of accident-prone Unit 2, the rate jumped to 17.2; it increased to 19.3 in the quarter following the accident at TMI and returned to 7.8 and 9.3, respectively, in the last two quarters of 1979.” (Dr. Gordon MacLeod, Secretary, Pennsylvania Department of Health).

In February 1983, 11,000 claims for lost wages and evacuation expenses were settled for $2.35 million.

July 24-27, 1984, during the 159-ton reactor head lift, which was delayed due to polar crane failure, GPU vented radioactive gases into the environment despite pledges by the company and the NRC that no radioactive releases would occur. This is the time there has been direct access to Unit-2’s damaged fuel. GPU was fined $40,000 by the NRC for this violation.

November 6, 1984 - Research conducted by the Department of Energy (DOE) on reactor damage during the accident, indicates temperatures may have reached in excess of 4,800 degrees. (See February 9, 1990, for follow-up research.)
1985 “TMI’s owners and builders had paid more than $14 million for out-of-court settlements of personal injury lawsuits. The largest settlement was for a child born with Down’s Syndrome. ($12.250 million paid to 280 plaintiffs and Orphans Court Cases.)

On July 12, 1985, two workers who participated in the initial phase of the cleanup and contracted cancer, joined 2,500 area residents suing GPU.

August, 1985: Marc Sheaffer, a psychologist at the Uniformed Services University of the Health Sciences in Bethesda, released a study linking TMI-related stress with immunity impairments. (See August, 1987 and April, 1988, for related studies.)

August, 1987: James Rooney and Sandy Prince of Embury of Penn State University reported that chronically elevated levels of psychological stress have existed among Middletown residents since the accident. (See August, 1985 and April, 1988, for related studies.)

April, 1988: Andrew Baum, professor of medical psychology at the Uniformed Services University of the Health Sciences in Bethesda discussed the results of his research on TMI residents in Psychology Today. “When we compared groups of people living near Three Mile Island with a similar group elsewhere, we found that the Three Mile Island group reported more physical complaints, such as headaches and back pain, as well as more anxiety and depression. We also uncovered long-term changes in levels of hormones...These hormones affect various bodily functions, including muscle tension, cardiovascular activity, overall metabolic rate and immune-system function...” (See August, 1985 and August, 1985, for related studies.)

1989: After ten years of defuelling activities, 5,000 TMI workers have received “measurable doses” of radiation exposure.

June, 1991: Columbia University’s Health Study (Susser-Hatch) published results of their findings in the American Journal of Public Health. The study actually shows a more than doubling of all observed cancers after the accident at TMI-2, including: lymphoma, leukemia, colon and the hormonal category of breast, endometrium, ovary, prostate and testis. For leukemia and lung cancers in the six to 12 km distance, the number observed was almost four times greater. In the 0-six km range, colon cancer was four times greater. The study found “a statistically significant relationship between incidence rates after the accident and residential proximity to the plant.” (See August, 1996 for Wing Study.)

By 1993, TMI-2 had evaporated 2.3 million gallons of accident generated radioactive generated water, including tritium a radioactive form of hydrogen (half life; 12.5 years), into the atmosphere despite legal objections from community-based organizations.

June 4, 1996 - U.S. District Judge Sylvia H. Rambo granted summary judgment to GPU and its co-defendants in consolidated proceedings of more than 2,000 personal injury claims arising from the March 1979 accident at TMI. (See August 1996, November 2, 1999 and June 12, 2000 for related health suit activities.)

August, 1996 - A study by the University of North Carolina-Chapel-Hill, authored by Dr. Steven Wing, reviewed the Susser-Hatch (Columbia University) study released in June 1991. Dr. Wing reported “…there were reports of erythema, hair loss, vomiting, and pet death near TMI at the time of the accident...Accident doses were positively associated with cancer incidence. Associations were largest for leukemia, intermediate for lung cancer, and smallest for all cancers combined...
...inhaled radionuclide contamination could differentially impact lung cancers, which show a clear dose-related increase.” (See June 4, 1996, November 2, 1999 and June 12, 2000, for related developments on TMI health claims.)

By 1996, the plant's owners, co-defendants and insurers have paid over $80 million in health, economic and evacuation claims, including a $1.1 million settlement for a baby born with Down's Syndrome.

November 2, 1999 - The Third Circuit Court of Appeals “revived the rest of the lawsuits [1,990], citing those individuals constitutional right to have their cases heard by a jury.” The Circuit Court upheld U.S. District Chief Judge Sylvia H. Rambo’s “ruling on the expert testimony and the dismissal of the 10 [test cases].” (Pennsylvania Law Weekly, June 12, 200). (Also refer to June 14 and August 1996 and June 12, for United States Supreme Court rejection of GPU’s appeals.)

June 12, 2000: The US Supreme Court, without comment, rejected an appeal by GPU to throw out 1,990 health suits. (Please refer to June 4 and August 1996 and November 2 1999, and May 2, 2001, for related developments.)

May 2, 2001: The Third Circuit Court ruled that “new theories” to support medical claims against Three Mile Island will not be allowed. (Please refer to June 4 and August 1996 and November 2 1999, and July 12, 2000, for related developments.)

Thyroid cancer, 1995-2002: Dr. Roger Levin, chief division of otolaryngology/head and neck surgery, PinnacleHealth System in Harrisburg, and clinical associate professor of surgery, Penn State College of Medicine. Levin did his research so he could join The Triological Society, a society for ear, nose and throat specialists and head and neck surgeons. His paper is scheduled to be published in the society's peer-reviewed journal, The Laryngoscope, in an upcoming month.

Findings: In reviewing state health data, Levin found more thyroid cancer cases than expected in York County for every year except one between 1995 and 2002. One plausible reason could be people were exposed to radiation during the 1979 Three Mile Island accident, he said.

November, 2003: “Objectivity and Ethics in Environmental Health Science” was published by Dr. Steve Wing, Department of Epidemiology, School of Public Health UN-Chapel Hill. Dr. Wing discussed “research into health effects of the 1979 accident at Three Mile Island...as an example of how scientific explanations are shaped by social concepts, norms and preconceptions” (Environmental Health Perspectives, Volume 111, Number 1 , November 2003, pp. 1809-1818).

Dr. Wing concluded:
"Many rural people living near TMI [Three Mile Island] had modest levels of formal schooling and little experience in being assertive with government and industry officials. Those that spoke about their experiences of physical problems from the accident endured ridicule. The Aamodts [Marjorie and Norman] were able to influence the TMI Public Health Fund’s sponsored research on physical impacts of the accident by initiating their own survey, researching government record, and petitioning the NRC. Other residents who lived within the 10-mile area also conducted surveys, constructed disease maps, and documented damage to plants and animals (Osborn 1996; TMI Alert 1999.)"
However, when health studies were undertaken through official channels, citizens who believed that they had been affected by accident emissions and their supporters were not included in the framing of the questions, study design, analysis, interpretation or communication of results. The studies themselves were funded by the nuclear industry and conducted under court-ordered constraints, and a priori assumptions precluded interpretation and observations as support for the hypotheses under investigation... The naive approach to objectivity, represented in the Daubert criteria, contends that scientists can produce unbiased evidence by standing apart from legal conflicts and adhering to normative science. The problem with this position is that scientific questions and the details of the specific working hypotheses emerge from conflicts, which also influence the assumptions that frame methodologies used to produce evidence and interpretations of the meaning of evidence... Pretending that there are no assumptions embedded in scientific methodology conceals and reinforces existing inequalities”
APPENDIX 1: Alice Stewart, epidemiologist
October 4 1906 to June 23 2002

Obituary of the Pioneering woman scientist whose research into the dangers of x-rays and nuclear radiation shook the establishment written by Anthony Tucker which appeared in the Guardian newspaper.

*********

Alice Stewart, who has died aged 95, achieved worldwide fame, and changed medical practice, through her tenacious investigations and demonstration of the connection between foetal x-rays and child cancers. She went on to attract the enmity of the nuclear and health physics establishments - and the hostility of the British and American governments - by insisting that her studies showed that the adverse effects of exposure to low-level radiation were far more serious than had been officially accepted.

She was also the first woman member of the Association of Physicians, and only the ninth (and youngest) to become a fellow of the Royal College of Physicians.

Stewart's entire life and career were devoted to social medicine, to the improvement of the lives of others, and to the bitter battles that have to be fought to ensure that findings contrary to policy or received wisdom - however important these may be to public or worker health - are investigated in a balanced and adequate way and, where necessary, acted upon.

Her pioneering work in industrial epidemiology, and on the effects of low-level radiation, earned her the 1986 Right Livelihood Award, the so-called "alternative Nobel prize" which is awarded by the Swedish parliament the day before the real Nobel, and the 1991 Ramazzini Award. In Britain, her findings on low-level radiation were regarded as so controversial that the British embassy even refused to send a car to collect her at the airport when she flew to Stockholm to receive the Livelihood prize.

Stewart was a brilliant student who matured into a gifted, decisive, tough, fearless and dedicated researcher. But she was also a lover of home, garden and countryside who, at a time of hostility toward professional women, managed to bring up a family while also carving out a career that reached international stature.

Born in Sheffield, where both her parents were doctors known for their interest in child welfare, she went from school to Girton College, Cambridge, to study medicine. She was, however, one of only four women among 300 men on her course, and recalled having to run the gauntlet of hostile male students stamping their feet in protest at the women's attendance at lectures.

Because, at that time, the Sheffield medical establishment did not accept women as hospital residents, Stewart went from university to the Royal Free hospital, in north London, for her clinical training. There, she mopped up the prizes, and revealed outstanding gifts for the diagnosis of rare conditions. After spells at the Manchester children's hospital and the London School of Hygiene, she became registrar in general medicine at the Royal Free, largely on the basis of her student record. It was an appointment without precedent, made, she later said, because she was "something of a whizz kid".

World war two found her working at the Elizabeth Garret Anderson hospital, in London, and then setting up an emergency clinical unit at St Albans. A trail of accidents and vacancies brought her to the Nuffield department of clinical medicine at Oxford, where, for the medical research council, she investigated the effects on workers of exposure to TNT in munitions factories, the effects of carbon tetrachloride, and the mysterious prevalence of tuberculosis among workers in the boot and shoe industry.

These studies revealed Stewart's brilliance in epidemiology and social medicine, and led, inevitably, to her involvement with the Oxford child health surveys, which had collected information on hundreds of thousands of children across Britain for 30 years.
Shortly after the war, she became involved in the Oxford child cancer studies. The incidence of child leukaemias was increasing in Britain at the time and, in 1955, it was suggested that there might be an environmental cause. Through analysis of the Oxford survey information, Stewart showed a clear connection between leukaemia before the age of 10 and the mother's exposure to x-rays during early pregnancy.

Resisted briefly by the medical profession, this finding later led to dramatic changes of practice. But it was aggressively opposed by many physicists and radiobiologists, by the committees of the international commission for radiation protection (ICRP), and by the powerful nuclear lobbies, within and outside government, that ICRP appeared to serve. The Oxford findings implied that low-level radiation - being imposed on nuclear workers and the public by fallout and nuclear-waste disposal - could be far more serious in its effects than had been officially admitted.

Stewart survived opposition and, already a professorial fellow at Lady Margaret Hall, Oxford, became director of the Nuffield institute of social medicine. Further analyses of the Oxford childhood cancer survey strengthened her initial findings. In the early 1970s, on the basis of these and other studies, she further infuriated the establishment by pointing out that, until the nature of radiation damage to genes was understood at the molecular level, predictions of second-generation and long-term genetic effects were premature.

While visiting the United States to discuss the Oxford survey findings in 1974, Stewart and her statistician, George Kneale, were invited by Professor TF Mancuso to become consultants on a major investigation he was directing for the US government into the health of nuclear workers at Hanford, the weapons complex that had produced plutonium for the Manhattan Project. Designed to parallel that of survivors of the Japanese A-bombs, this long-term study became known as the Hanford survey.

At that time, it was the largest of its kind into the long-term health effects of low-level radiation on workers in the nuclear industry. Since the industry was required by law to work within the exposure levels laid down by the ICRP, the study was seen as a test of these standards, as well as an investigation of worker health. The Stewart-Kneale analysis revealed roughly 10 times the cancer incidence predicted from A-bomb survivor studies.

An immediate and damning official outcry ensued. Mancuso was deprived of his directorship by the US government; the first full survey results were never published in their original form; and the use of outside consultants was promptly banned.

In spite of this, the Hanford survey, and Stewart's collaborative studies, continued. Information was added year by year, many of the early criticisms of the study were eliminated, and the findings, although modified, remained largely unchanged. They suggested adult sensitivity to radiation broadly in line with the findings of the Oxford child cancer survey - roughly 10 times the official figures.

Much of this work was carried out after Stewart's retirement from Oxford, when she became senior research fellow in the department of social medicine at Birmingham University. Her unit was housed in a caravan; she was deprived of research support from British sources; and, although her findings increasingly gathered approval elsewhere in the world, she and her work were subjected in Britain to professional isolation - and often to malicious, and unjustified, attacks.

However, grants continued to flow from the United States and elsewhere. With characteristic energy and brisk determination, Stewart commuted up the motorway year after year from her cottage in Oxfordshire to continue the study and reanalysis of the growing body of information. It was difficult, but she always smiled when asked why she went on when recognition eluded her in her own country. "Good people are seldom fully recognised during their lifetimes, and here, there are serious problems of corruption. One day it will be realised that my findings should have been acknowledged."

In her later years, because of official recalculation of radiation doses to the Japanese bomb survivors, she was able to nod knowingly as ICRP guidelines on permitted levels of radiation for the public were reduced by two
thirds. New evidence of the highly localised molecular damage produced by radiation in genetic material also reinforced her findings of high sensitivity during foetal development and of second-generation effects.

Sitting in her cottage or, preferably, out in its leafy garden where, when they were young, her grandchildren would play before having tea with home-made jam, Stewart would reflect quietly that the world was beginning to learn. “Plants get all their energy from the sun and so should we,” she would say. Then she would smile wistfully, for she knew how very long that learning curve might be.

She married her husband Ludovick in 1933; they divorced in the 1950s. She is survived by her daughter, a doctor in general practice; her son predeceased her.

This obituary has been revised since the writer’s death.
APPENDIX 2: Conference background

Low Level Radiation and Health Conference

In brief, the Low Level Radiation and Health Conference was set up in 1985 by members of the public keen to find out more about these issues and so 2008 will see it celebrate 23 years since it started. Since its inception, the conference has been organised annually by a different voluntary group of members of the public and the event has rotated to different parts of the UK.

The conference is a unique event bringing together members of the nuclear industry, Government organisations, monitoring agencies, Local authorities, medics, academic researchers, health workers, environmental health officers, campaigners and interested lay people. It is an educational event which aims to provide up to the minute research via presentations by a range of people from government, regulators, industry and academics thus making these issues accessible to as broad a range of people as possible by keeping the costs as low as reasonably practicable.

Dr Alice Stewart (AMS) – the doyenne of low level radiation research - gave her support unstintingly from the beginning realising that her name would give some authority to the event. She also regularly presented her latest findings at it. In 1994 we named a keynote lecture in her honour.

1985: No 1: Gloucester organised by SCAR, Barbara French and Sue Havely- Alice talks on the Medical Effects of Radiation.
1986: No 2: Barrow, Cumbria organised by Cumbrians Opposed to a Radioactive Environment (CORE) AMS presentation on Pre-natal X-rays and A-bomb data
1987: No 3: Grantham
1988: No 4: Stirling
1989: No 5: Norwich, East Anglia organised by member of the East Anglian Alliance Against Nuclear power (EAANP)
1990: No 6: Bangor, organised by members of the Welsh Anti Nuclear Alliance (WANA) including Hugh Richards (see workshops) with support from Gwynedd County Council
1991: No 7: Bristol, hosted by Bristol City Council and organised by the Conference Organising Group comprising Low Level Radiation and Health, SCAR, Bristol City Council, Ann Case (radiographer) and Brian and Ros Rome; AMS speaks on Hanford data and the workforce
1992: No 8: Newcastle organised by John Urquhart, Librarian at Newcastle University
1993: No 9: Liverpool organised with local help from Graham Thorne
1994: No 10: Glasgow - Organised by Rita Holmes and Margaret Crankshaw. Opening lecture dedicated Alice and called the Alice Stewart lecture Alice in attendance together with Faith.
1995 No 11 Carlisle, organised by CORE, AMS speaks on possible fallacies in cancer risk estimates.
1996 Portsmouth University: Conference on Radiation and Health near nuclear power stations, July 9-12, organised by Dr Michael Schmidt jointly with the German Society for Radiation Protection and Alice Stewart gave presentation on A-bomb survivors.
1997 No 12: Bristol, University of West of England organised by Paul Dorfman et al
1998 No 13: Greenwich organised by Rebecca Harrison, AMS speaks about neglected aspects of Atomic Bomb Survivors
1999 No 14: Lancaster University organised by CORE, Janine Alys-Smith
2000 No 15: Reading, NAG including Pam Vassie and Di McDonald
2001 No 16: Workshop presentation on ethics, Manchester organised by Dr Cat Euler - Dr Deborah Oughton, Associate Professor, Dept of Chemistry and Biotechnology
2002 No 17: Dublin, Dr Carmel Mothersill, Radiation and Environmental Science Centre, Dublin Institute of Technology
2003  None held

2004:  No 18: Edinburgh, Dr Keith Baverstock - 20 years on, Science, ethics and politics in the low dose debate.

2006:  No 19: Hamilton, Canada, Professor Colin Seymour, Low Dose Radiation and Risk

2008:  No 20: University of Cumbria, Ambleside, Dr Wolfgang-Ulrich Mueller, Institute for Medical Radiation Biology, University of Essen, Radiation-induced Pregnancy Effects

2010:  No 21: Friends Meeting House, Manchester arranged with the Nuclear Free Local Authorities.
Alice Stewart lectures

When I rang Alice in 1994 I was careful to point out that we wanted her to live for ages. Such lectures are usually named after someone when they have died. When I asked her if we could instigate such a lecture she burst out laughing and said she’d be delighted and that it was the first honour given to her in the UK. As members of the public we were so proud, as scientists and health workers we were astonished at this lack of national recognition. The lectures have been given by the following eminent scientists:

1994: **Dr Tom Wheldon**, Glasgow: *Radiation and Cancer genes*
1995: **Dr Eric Wright**, Medical Research Council - *Alpha particle irradiation and genomic instability*
1996: **Presentations at Portsmouth included one by Alice on her work on A-Bomb survivors and risk factors**
1997: **Dr Alan Irwin**, Brunel University - *Citizen Science*
1998 **Professor Andrew Blowers**, Open University and a member of RWMAC – *Nuclear waste issues*
1999 **Dr Rosalie Bertell**, Institute for Public Health, Toronto spoke on *Breast Cancer and Radiation*. Alice was unable to attend for once and sent her regards to everyone
2000 **Dr Carol Barton**, haematologist *Royal Berkshire Hospital study on Aldermaston + Burghfield*
2001 **Dr Deborah Oughton** on *Ethics and radiation* at workshop
2002 **Dr Steve Wing**, University of Carolina on *Epidemiological studies*
2003: None given
2004: **Dr Keith Baverstock** formerly of World Health Organisation gave the opening lecture, *20 years on – Science, ethics and politics in the low dose debate*
2006: **Professor Colin Seymour** from McMaster University, Hamilton, Canada
2008: **Dr Wolfgang-Ulrich Mueller**, Institute for Medical Radiation Biology, University of Essen, *Radiation-induced Pregnancy Effects*
2010: **Professor Wolfgang Weiss**
## Appendix 3: Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Meaning</th>
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<tr>
<td><strong>A</strong></td>
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<tr>
<td>Absorbed dose</td>
<td>Quantity of energy imparted by ionising radiation to unit mass of matter such as tissue. Unit gray, symbol Gy. 1 Gy = joule per kilogram.</td>
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<tr>
<td>Activity Concentration</td>
<td>The activity per unit mass or volume, e.g. Bq kg⁻¹, Bq l⁻¹</td>
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<tr>
<td>AECL</td>
<td>Atomic Energy Canada Limited</td>
</tr>
<tr>
<td>ALARA</td>
<td>&quot;As low as reasonably achievable&quot;, refers to actions directed to limiting doses to individuals, the number of exposed individuals, and the probability of receiving a dose.</td>
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<tr>
<td>Allometry</td>
<td>Relationships between body mass of organisms and various parameters (including of relevance to PROTECT radionuclide biological half-life and dietary dry matter intake).</td>
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<tr>
<td>Assessment Endpoint</td>
<td>The biological effect inferred from measurements or predictions and which the assessment framework is designed to study.</td>
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<tr>
<td>Assessment factor</td>
<td>Allowance for degree of uncertainty, caused by lack of effects data. For example, an estimated lowest observed effect concentration may, as a precautionary approach, be divided by a assessment factor (normally within the range of 10 to 10000) to safeguard against harmful effects, where the magnitude of the assessment factor reflects the degree and type of uncertainty (e.g. lack of chronic exposure data, lack of data for different taxonomic groups or trophic levels, etc.). The assessment factor (AF) is also known as the safety factor.</td>
</tr>
<tr>
<td>Assessment Framework</td>
<td>Identification and demarcation of the assessment boundaries. In FASSET, the framework contains the process from problem formulation through to characterisation of the effects of radiation on individuals. The overall assessment system describes the tools, methods and information flow used to carry out the impact assessment.</td>
</tr>
<tr>
<td>Authorisation</td>
<td>The granting by a regulatory body or other governmental body of written permission for an operator to perform specified activities.</td>
</tr>
<tr>
<td><strong>B</strong></td>
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</tr>
<tr>
<td>BAT</td>
<td>Best Available Technology: a term applied to abatement technology designed to limit pollutant discharges. The term constitutes a moving target on practices, since developing societal values and advancing techniques may change what is currently regarded as 'best available'. Similar terms include 'best practicable means' and 'best practicable environmental option'.</td>
</tr>
<tr>
<td>BCG</td>
<td>Biota Concentration Guidelines: the media concentration for which the corresponding dose rate is equal to the screening dose rate used in the USDoE's graded approach and RESRAD-BIOTA assessment tool.</td>
</tr>
<tr>
<td>BCG calculator</td>
<td>Biota Concentration Guidelines calculator: A semi-automated tool for implementing screening and analysis methods contained within the USDoE graded approach. Although the BCG calculator is still available RESRAD-BIOTA has been developed to replace it.</td>
</tr>
<tr>
<td>Benchmark</td>
<td>Risk assessment benchmarks are the concentrations, doses or dose rates that are estimated to equate to predefined criteria (e.g. predicted no effects dose rate, severe risk) based on exposure-response information and political/societal decisions.</td>
</tr>
<tr>
<td>Bioaccumulation</td>
<td>The process whereby an organism accumulates substances in living tissues to concentrations higher than those existing in the surrounding media.</td>
</tr>
<tr>
<td>Bioassay</td>
<td>A test to determine the relative strength of a substance by comparing its effect on a test organism with that of a standard preparation.</td>
</tr>
<tr>
<td>Bioavailability</td>
<td>Defined as the fraction of the contaminant that can be taken up by living organisms, dependant both on the chemical speciation of the exposure source(s) and on the physiological status of the organism.</td>
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<tr>
<td>Term</td>
<td>Description</td>
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<tr>
<td><strong>Biodiversity</strong></td>
<td>The number and abundance of species found within a common environment. This includes the variety of genes, species, ecosystems, and the ecological processes that connect everything in a common environment.</td>
</tr>
<tr>
<td><strong>Biological half-life</strong></td>
<td>The time required for a biological system (e.g. an animal) to eliminate, by natural processes, half the amount of a substance that has been absorbed into that system.</td>
</tr>
<tr>
<td><strong>Biomagnification</strong></td>
<td>Situations where the concentration of certain substances increases up the food chain.</td>
</tr>
<tr>
<td><strong>Biosphere</strong></td>
<td>That part of the environment normally inhabited by living organisms. In practice, the biosphere is not usually defined with great precision, but is generally taken to include the atmosphere and the Earth's surface, including the soil, surface water bodies, seas and oceans and their sediments. There is no generally accepted definition of the depth below the surface at which soil or sediment ceases to be part of the biosphere, but this might typically be taken to be the depth affected by basic human actions, particularly farming. In waste safety in particular, the biosphere is normally distinguished from the geosphere.</td>
</tr>
<tr>
<td><strong>BPEO</strong></td>
<td>Best Practicable Environmental Option, see BAT.</td>
</tr>
<tr>
<td><strong>BPM</strong></td>
<td>Best Practicable Means, see BAT.</td>
</tr>
<tr>
<td><strong>BWG</strong></td>
<td>Biota Working Group: Part of the IAEA EMRAS programme aimed at comparing and validating models used and developed by member states for biota dose assessments that may be used as part of a regulatory processes concerning authorised releases of radionuclides in order to improve Member States' capabilities for protection of the environment.</td>
</tr>
<tr>
<td><strong>Bystander Effect</strong></td>
<td>Cells adjacent to those hit by ionising radiation show effects of impact.</td>
</tr>
<tr>
<td><strong>Conceptual model</strong></td>
<td>Representation of the environmental system and of the physico-chemical and biological processes that determine the transport/transfer of contaminants from sources through environmental media to ecological receptors within the system.</td>
</tr>
<tr>
<td><strong>Contaminant</strong></td>
<td>Any physical, chemical, biological, or radiological substance or matter that has a potentially adverse effect on air, water, or soil, with the implication that the amount is measurable.</td>
</tr>
<tr>
<td><strong>CR</strong></td>
<td>Concentration ratio: ratio used to quantify the equilibrium between an environmental medium and a living organism (e.g., water to fish CR). Sometimes referred to as concentration factor or bioaccumulation factor.</td>
</tr>
<tr>
<td><strong>Cytogenetic effect</strong></td>
<td>An observed effect in chromosomes that can be correlated with adverse hereditary effects or genetic effects (effects that are inheritable and appear in the descendants of those exposed).</td>
</tr>
<tr>
<td><strong>DCC</strong></td>
<td>Dose Conversion Coefficient expressed as Gy per kg of the target organism per Bq per unit of mass or volume of the source. The DCC is specific to each radionuclide and organism and was calculated for external and internal exposure. Sometimes referred to as the Dose Conversion Factor.</td>
</tr>
<tr>
<td><strong>DCF</strong></td>
<td>Dose Conversion Factor, see Dose Conversion Coefficient.</td>
</tr>
<tr>
<td><strong>DCL</strong></td>
<td>Derived consideration level: A band of absorbed dose rate for each Reference Animal and Plant within the ICRP proposed framework. These do not represent dose limits but a range of doses which form a starting point from which dose limits may be considered in the future.</td>
</tr>
<tr>
<td><strong>Dispersion model</strong></td>
<td>Model for the representation of the spreading of radionuclides in air (aerodynamic dispersion) or water (hydrodynamic dispersion) resulting mainly from physical processes affecting the velocity of different molecules in the medium.</td>
</tr>
<tr>
<td><strong>Dose</strong></td>
<td>See absorbed dose.</td>
</tr>
<tr>
<td><strong>Dose constraint</strong></td>
<td>A restriction on annual dose to an individual (human), which may either relate to a single dose or to a complete site, in order to ensure that when aggregated with doses from all sources, excluding natural background and medical procedures, the dose limit is not exceeded.</td>
</tr>
<tr>
<td><strong>Dose rate</strong></td>
<td>Dose (normally absorbed dose) received over a specified unit of time.</td>
</tr>
<tr>
<td><strong>Dose-effect</strong></td>
<td>The relationship between dose (usually an estimate of dose) and the gradation of the effect in an exposed population, that is a biological change measured on a graded scale of severity.</td>
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<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>Dose-response</td>
<td>A correlation between a quantified exposure (dose) and the proportion of an exposed population that demonstrates a specific effect (response).</td>
</tr>
<tr>
<td>Dosimetry</td>
<td>The measurement and calculation of radiation dose in matter and tissue resulting from exposure to ionising radiation.</td>
</tr>
<tr>
<td>DWB</td>
<td>Direct Weighted Bootstrap</td>
</tr>
<tr>
<td>EA R&amp;D 128</td>
<td>Radiological assessment approach for wildlife and associated tool developed by the England and Wales Environment Agency.</td>
</tr>
<tr>
<td>Ecological impact</td>
<td>The total effect of an environmental change, natural or man-made, on the community of living organisms.</td>
</tr>
<tr>
<td>Ecological Receptor</td>
<td>Living organisms at various organisational levels (i.e. ecosystems, communities, populations, individual organisms) potentially exposed to and adversely affected by stressors because they are present in the source(s) and/or along stressor migration pathways. This term dose not refer to humans.</td>
</tr>
<tr>
<td>Ecosystem</td>
<td>The interacting system of a biological community and its nonliving surroundings.</td>
</tr>
<tr>
<td>ECx</td>
<td>Effect Concentration: the concentration of a chemical required to cause a given effect to x% of a population or community. For example, EC10: concentration of a chemical required to cause a given effect in 10% of a population or community.</td>
</tr>
<tr>
<td>EDRx</td>
<td>Effects Dose Rate: the radiation dose rate required to cause a given effect to x% of a population or community. For example, EDR10: the dose rate required to cause a given effect in 10% of a population or community. Effect A biological change caused by an exposure. Strictly speaking, an effect is the change in an endpoint under consideration when it is compared to a control.</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>EMRAS</td>
<td>Environmental Modelling for Radiation Safety: An IAEA programme aimed at improving models for the purposes of radiation protection of the public and the environment ([<a href="http://www-ns.iaea.org/projects/emras">http://www-ns.iaea.org/projects/emras</a>]).</td>
</tr>
<tr>
<td>EMCLS</td>
<td>Environmental Media Concentration Limits: Used as part of the ERICA Tool and defined as the activity concentration in the selected media (soil, air, water or sediment) that would result in a dose-rate to the most exposed reference organism equal to that of the selected screening dose-rate.</td>
</tr>
<tr>
<td>Endpoint</td>
<td>In toxicity testing and evaluation it is the biological response that is measured. Endpoints vary with the level of biological organisation being examined and include responses at the subcellular level to the community level such as biomarkers (subcellular level), survival, growth, reproduction (individual level), primary production, and structure (abundance) and function in a community (population or community level). Endpoints are used in toxicity tests as criteria for effects.</td>
</tr>
<tr>
<td>ENEV</td>
<td>Environmental No Effects Value: a dose level at which a population of organisms will not be affected (defined by Environment Canada).</td>
</tr>
<tr>
<td>Environment</td>
<td>Water, air, land, plants and man and all other organisms living therein, and the interrelationships which exist among them.</td>
</tr>
<tr>
<td>EIS</td>
<td>Environmental Impact Statement: a document providing information for decision makers on the positive and negative effects of an action, practice or policy, which identifies and evaluates the environmental impacts of the hazard source and feasible alternatives, including taking no action.</td>
</tr>
<tr>
<td>Environmental Justice</td>
<td>Often used interchangeably with the term environmental equity, refers to the distribution and effects of environmental problems and the policies and processes to reduce differences in who bears environmental risks. In a general sense, it includes concern for disproportionate risk burden placed upon any population group, as defined by gender, age, income, race, nationality or generation.</td>
</tr>
<tr>
<td>Environmental quality criteria</td>
<td>The levels of pollution and lengths of exposure, above which adverse effects may occur on health and welfare.</td>
</tr>
<tr>
<td>Environmental</td>
<td>The level of contaminants prescribed by law or regulation that cannot be quality standards exceeded during a specified time in a defined area.</td>
</tr>
<tr>
<td>EQSs</td>
<td>Environmental Quality Standards</td>
</tr>
<tr>
<td>ERA</td>
<td>Ecological Risk Assessment</td>
</tr>
<tr>
<td><strong>ERICA</strong></td>
<td>Environmental Risk from Ionising Contaminants: Assessment and Management, EURATOM 6th Framework project.</td>
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<tr>
<td><strong>ERICA Tool</strong></td>
<td>A tool implementing the ERICA tiered approach for radiological assessment of wildlife in freshwater, terrestrial and marine ecosystems developed by an EURATOM 6th Framework consortium.</td>
</tr>
<tr>
<td><strong>EURATOM</strong></td>
<td>European Atomic Energy Community</td>
</tr>
<tr>
<td><strong>Exposure</strong></td>
<td>The co-occurrence or contact between the endpoint organism and the stressor (e.g. radiation or radionuclide).</td>
</tr>
<tr>
<td><strong>Exposure Assessment</strong></td>
<td>The process of measuring or estimating the intensity, frequency, and duration of exposures to an agent currently present in the environment or of estimating hypothetical exposures that might arise from the release of new chemicals into the environment.</td>
</tr>
<tr>
<td><strong>Exposure pathway</strong></td>
<td>A route by which radiation or radionuclides can reach humans and cause exposure - an exposure pathway may be very simple, e.g. external exposure from airborne radionuclides, or a more complex chain.</td>
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<tr>
<td><strong>F</strong></td>
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<tr>
<td><strong>FASSET</strong></td>
<td>Framework for Assessment of Environmental Impact EURATOM 5th Framework project examining impact of radiation on wildlife or non-human biota.</td>
</tr>
<tr>
<td><strong>Feature species</strong></td>
<td>see reference organisms</td>
</tr>
<tr>
<td><strong>Fecundity</strong></td>
<td>The number of viable offspring produced by an organism; mature seeds produced, eggs laid, or live offspring delivered, excluding fertilised embryos that have failed to develop.</td>
</tr>
<tr>
<td><strong>Fertility</strong></td>
<td>The ability to produce offspring.</td>
</tr>
<tr>
<td><strong>Foundation species</strong></td>
<td>Highly interactive species that are often extremely abundant or ecologically dominant.</td>
</tr>
<tr>
<td><strong>FREDERICA</strong></td>
<td>The FASSET Radiation Effects Database (FRED) which has been updated through the addition of a quality scoring exercise of each literature source to evaluate how useable the data is in the context of defining dose (rate) effect relationships for incorporation into the SSD and other approaches. In addition new literature sources have been added to the database and it has been updated to make it available on the internet. It has been renamed as the FREDERICA database in recognition of these changes (<a href="http://www.frederica-online.org">www.frederica-online.org</a>).</td>
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<td><strong>G</strong></td>
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<tr>
<td><strong>Gamma air kerma</strong></td>
<td>Gamma air kerma is exposure measured in air which is in effect, the absorbed dose measured in air. See Kerma.</td>
</tr>
<tr>
<td><strong>Genomic Instability</strong></td>
<td>Effects of ionising radiation on cells following multiplication. It could have been that a cell died or there was not effect. Instead, effects after 1 alpha particle traversed a cell include damage to daughter cells.</td>
</tr>
<tr>
<td><strong>H</strong></td>
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<tr>
<td><strong>Hazard</strong></td>
<td>A condition or physical situation with a potential for an undesirable consequence, such as harm to health or environment.</td>
</tr>
<tr>
<td><strong>Hazard analysis</strong></td>
<td>Procedure used to (1) identify potential sources of release of hazardous materials from fixed facilities or transportation accidents; (2) determine the vulnerability of a geographical area to a release of hazardous materials; and (3) compare hazards to determine which present greater or lesser risks to a community.</td>
</tr>
<tr>
<td><strong>Hazard Identification</strong></td>
<td>Recognising that a hazard exists and trying to define its characteristics. The process of determining whether exposure to an agent can cause an increase in the incidence of an adverse health or environmental effect.</td>
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<tr>
<td><strong>HDRx</strong></td>
<td>Hazardous Dose (rate) affecting x% of the species of a given ecosystem. This value is estimated from the Species Sensitivity Distribution.</td>
</tr>
<tr>
<td><strong>HNED(R)</strong></td>
<td>The highest no effect dose or dose rate in a toxicity test that does not causes a statistically significant effect in comparison to the control. The same definition applies for Concentration. See NOEC.</td>
</tr>
<tr>
<td><strong>Hormetic pattern</strong></td>
<td>Pattern of dose response where there is an initial 'positive' effect at low concentrations of a chemical or low radiation dose rates, followed by a progressive negative effect at higher concentrations or dose rates.</td>
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<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td><strong>IAEA</strong></td>
<td>International Atomic Energy Agency, see <a href="http://www.iaea.org">www.iaea.org</a></td>
</tr>
<tr>
<td><strong>ICRP</strong></td>
<td>International Commission on Radiological Protection, see <a href="http://www.icrp.org">www.icrp.org</a></td>
</tr>
<tr>
<td><strong>Indicator Organisms</strong></td>
<td>A species, whose presence or absence may be characteristic of environmental conditions in a particular area of habitat; however, species composition and relative abundance of individual components of the population or community are usually considered to be a more reliable index of water quality.</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>Distribution Coefficient used to quantify the equilibrium between solid and liquid phases (soil or sediment-interstitial water), usually expressed in l kg⁻¹. It is the ratio of the mass of the solute species adsorbed (or precipitated) on the solid particles per unit of dry mass of the soil or sediment to the solute concentration in the liquid phase. It represents the partition of the solute in the soil or sediment matrix and soil or sediment water, assuming that equilibrium conditions exist between the solid and liquid phases. The Kd values are dependent on the soil or sediment physical and chemical characteristics.</td>
</tr>
<tr>
<td><strong>Kerm</strong></td>
<td>Kerma is the kinetic energy released in material measured in Gy. Kerma can be quoted for any specified material at a point in free space or in an absorbing medium. See gamma air kerma.</td>
</tr>
<tr>
<td><strong>Keystone species</strong></td>
<td>A species that plays a critical role in maintaining the structure of an ecological community and whose impact on the community is greater than would be expected based on its relative abundance or total biomass.</td>
</tr>
<tr>
<td><strong>LEL</strong></td>
<td>Lowest Effect Level</td>
</tr>
<tr>
<td><strong>LOEC, LOED(R)</strong></td>
<td>The lowest observed effect concentration in a toxicity test that causes a statistically significant effect in comparison to the control. The same definition applies for Dose or Dose Rate (in place of Concentration).</td>
</tr>
<tr>
<td><strong>Measurement endpoint</strong></td>
<td>Measured or predicted value that an assessment produces.</td>
</tr>
<tr>
<td><strong>Morbidity</strong></td>
<td>A loss of functional capacities generally manifested as reduced fitness, which may render organisms less competitive and more susceptible to other stressors, thus reducing the life span.</td>
</tr>
<tr>
<td><strong>Mortality</strong></td>
<td>Death; the death rate; ratio of number of deaths to a given population.</td>
</tr>
<tr>
<td><strong>NATURA 2000 Site</strong></td>
<td>A protected ecological area within the EU containing threatened habitats and/or species.</td>
</tr>
<tr>
<td><strong>Natural Background</strong></td>
<td>The doses, dose rates or activity concentrations associated with natural sources or any other sources in the environment which are not amenable to control. This is usually considered to include doses, dose rates or concentrations due to natural sources but may also include global fallout (but not local fallout) from atmospheric nuclear weapon tests and depending upon context, fallout from incidents such as the Chernobyl accident.</td>
</tr>
<tr>
<td><strong>NCRP</strong></td>
<td>National Council on Radiation Protection and Measurements, see <a href="http://www.ncrponline.org">www.ncrponline.org</a></td>
</tr>
<tr>
<td><strong>NEA</strong></td>
<td>Nuclear Energy Agency. A specialised agency within the Organisation for Economic Co-operation and Development (OECD). See <a href="http://www.nea.fr">www.nea.fr</a> No effect concentration, see NOEC, NOED(R)</td>
</tr>
<tr>
<td><strong>NGO</strong></td>
<td>Non-Governmental Organisation</td>
</tr>
<tr>
<td><strong>NoE</strong></td>
<td>Network of Excellence: EC funding mechanism</td>
</tr>
<tr>
<td><strong>NOEC, NOED(R)</strong></td>
<td>No observed effect concentration is the highest concentration in a toxicity test not causing a statistically significant effect compared with the control. The same definition applies for Dose or Dose Rate (in place of Concentration). See also HNEDR.</td>
</tr>
<tr>
<td><strong>NPP</strong></td>
<td>Nuclear Power Plant</td>
</tr>
<tr>
<td><strong>OECD</strong></td>
<td>Organisation for Economic Co-operation and Development, see <a href="http://www.oecd.org">www.oecd.org</a></td>
</tr>
</tbody>
</table>
**Occupancy factors**
The maximum fraction of time during which individuals may be exposed to a given dose rate of ionising radiation.

**OSPAR**
The mechanism by which 15 governments of the western coasts and catchments of Europe, together with the EC, cooperate to protect the marine environment of the North-East Atlantic.

**P**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNED(R)</td>
<td>Predicted No-Effect Dose (Rate) expressed in Gy or Gy per unit of time.</td>
</tr>
<tr>
<td>PNEC</td>
<td>Predicted No-Effect Concentration, see NOEC, NOED(R) for No Effect Concentration.</td>
</tr>
<tr>
<td>Precautionary Principle</td>
<td>The precautionary principle applies where scientific evidence is insufficient, inconclusive or uncertain and preliminary scientific evaluation indicates that there are reasonable grounds for concern that the potentially dangerous effects on the environment, human, animal or plant health may be inconsistent with the desired level of protection.</td>
</tr>
<tr>
<td>PROTECT</td>
<td>Protection of the Environment from Ionising Radiation in a Regulatory Context</td>
</tr>
<tr>
<td>Protection goal</td>
<td>The measurable aims of environmental protection</td>
</tr>
</tbody>
</table>

**R**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation weighting factors</td>
<td>Factor (numeric value) which represents the relative biological effectiveness of the different radiation types, relative to X- or gamma-rays, in producing endpoints of ecological significance.</td>
</tr>
<tr>
<td>Radioactive Material</td>
<td>Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity.</td>
</tr>
<tr>
<td>Radioactive Substance</td>
<td>A substance that emits ionising radiation. See also radioactive material.</td>
</tr>
<tr>
<td>Radioecological Sensitivity</td>
<td>A combination of features which includes biology and habits of an organism, that contribute to the likelihood of an organism being exposed to radioactive substances in its environment.</td>
</tr>
<tr>
<td>Radionuclide</td>
<td>An unstable nuclide that undergoes spontaneous transformation, emitting ionising radiation.</td>
</tr>
<tr>
<td>RAP</td>
<td>Reference Animals and Plants: Group of 12 reference organisms proposed as part of the ICPR framework.</td>
</tr>
<tr>
<td>RBE</td>
<td>Relative Biological Effectiveness: For a given type of radiation, the RBE is the dose of the reference radiation needed to produce the same effect dose of the given radiation needed to produce a given biological effect.</td>
</tr>
<tr>
<td>REACH</td>
<td>Registration, Evaluation and Authorisation of Chemicals and EU regulatory framework</td>
</tr>
<tr>
<td>Receptor</td>
<td>See ecological receptor</td>
</tr>
<tr>
<td>Reference Organisms</td>
<td>A series of entities that provide a basis for the estimation of radiation dose rate to a range of organisms that are typical or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects.</td>
</tr>
<tr>
<td>Relative Biological Response</td>
<td>The proportion or absolute size of an exposed population that demonstrates a specific effect. May also refer to the nature of the effect.</td>
</tr>
<tr>
<td>RESRAD-BIOTA</td>
<td>Radiological assessment tool which implements the USDOE's graded approach for evaluating radiation doses to freshwater and terrestrial biota.</td>
</tr>
<tr>
<td>Risk</td>
<td>A statistical concept describing the expected frequency or probability of undesirable effects arising from exposure to a contaminant. A measure of the probability that damage to life, health, property, and/or the environment will occur as a result of a given hazard. A technical estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence or magnitude of the event given that it has occurred.</td>
</tr>
<tr>
<td>Risk assessment</td>
<td>A qualitative or quantitative evaluation of the risk posed to human health and/or the environment by the actual and/or potential presence of contaminants. It includes problem formulation, exposure and dose-response assessment and risk characterisation.</td>
</tr>
<tr>
<td>Risk characterisation</td>
<td>The synthesis of information obtained during risk assessment for use in management decisions. This should include an estimation of the probability (or incidence) and magnitude (or severity) of the adverse effects likely to occur in a population or environmental compartment, together with identification of uncertainties.</td>
</tr>
<tr>
<td>Risk</td>
<td>The exchange of information about health or environmental risks among risk assessors and managers, the general...</td>
</tr>
<tr>
<td><strong>communication</strong></td>
<td>public, news media, interest groups, etc.</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td><strong>Risk evaluation</strong></td>
<td>A component of risk assessment in which judgments are made about the significance and acceptability of risk.</td>
</tr>
<tr>
<td><strong>Risk management</strong></td>
<td>The selection and practical implementation of regulatory and non-regulatory responses to risk. Practical implementation of procedures, actions or policies to mitigate, reduce, remove or monitor health or environmental risk.</td>
</tr>
<tr>
<td><strong>RQ</strong></td>
<td>Risk Quotient: ratio of predicted dose rate to benchmark dose rate.</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Safety factors</strong></td>
<td>See assessment factor.</td>
</tr>
<tr>
<td><strong>Screening assessment</strong></td>
<td>Simple and generally highly conservative assessment tier.</td>
</tr>
<tr>
<td><strong>Screening value</strong></td>
<td>As used by the ERICA and PROTECT projects the screening value is equivalent to the PNED(R).</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>Standard Deviation</td>
</tr>
<tr>
<td><strong>SETAC</strong></td>
<td>Society of Environmental Toxicology and Chemistry</td>
</tr>
<tr>
<td><strong>Source</strong></td>
<td>Anything that may cause radiation exposure — such as by emitting ionising radiation or by releasing radioactive substances or materials — and can be treated as a single entity for protection and safety purposes.</td>
</tr>
<tr>
<td><strong>SSD</strong></td>
<td>Species Sensitivity Distribution establishing the statistical distribution of the radiosensitivity of species.</td>
</tr>
<tr>
<td><strong>Sustainability</strong></td>
<td>The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time.</td>
</tr>
<tr>
<td><strong>Synergism</strong></td>
<td>An interaction between two substances that results in a greater effect than both of the substances could have had acting independently.</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td></td>
</tr>
<tr>
<td><strong>TeNORM</strong></td>
<td>Technologically-Enhanced Naturally Occurring Radioactive Material. Refers to radioactive materials that occur naturally but which have been exposed or concentrated by human activity.</td>
</tr>
<tr>
<td><strong>Threshold</strong></td>
<td>A contaminant concentration (or dose), below which no deleterious effect occurs.</td>
</tr>
<tr>
<td><strong>Tiered assessment</strong></td>
<td>Approach involving progressively detailed tiers of assessment generally starting with highly conservative and simple ('screening') assessments and progressing through more detailed realistic tiers if warranted.</td>
</tr>
<tr>
<td><strong>Toxicant</strong></td>
<td>A substance that kills or injures an organism through chemical or physical action or by altering the organism's environment; for example, cyanides, phenols, pesticides, or heavy metals; especially used for insect control.</td>
</tr>
<tr>
<td><strong>Trigger value</strong></td>
<td>See screening value</td>
</tr>
<tr>
<td><strong>U</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Uncertainty</strong></td>
<td>This arises from imprecision due to lack of information, expert judgement and/or measurement errors and could be reduced with increased knowledge and/or experimentation.</td>
</tr>
<tr>
<td><strong>UNSCEAR</strong></td>
<td>United Nations Scientific Committee on the Effects of Atomic Radiation</td>
</tr>
<tr>
<td><strong>USDOE graded approach</strong></td>
<td>United States Department of Energy graded approach for evaluating radiation doses to aquatic and terrestrial biota.</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Valued ecosystem components</strong></td>
<td>Assessed species selected for both scientific and public interest reasons.</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td></td>
</tr>
<tr>
<td><strong>WFD</strong></td>
<td>Water Framework Directive. EC water legislation for integrated river basin management.</td>
</tr>
<tr>
<td><strong>Wildlife</strong></td>
<td>All non-domesticated plants, animals and other organisms.</td>
</tr>
</tbody>
</table>