Evidence of significant enriched uranium atomic fuel contamination of the Hinkley Point proposed nuclear site in Somerset and its potential implications

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1. Background

The French company, Electricite de France (EDF Energy) has recently proposed building new nuclear power reactors on a site adjacent to the Hinkley Point nuclear power station complex in Somerset. As part of their project, they commissioned AMEC to take samples and make measurements of radioactivity at various locations on the proposed site for the new plant. The results have been published in a number of documents. One purpose of the analyses was to provide a baseline natural background against which future levels of radioactivity released from any new plant could be compared. A subsidiary issue has been to determine whether the current levels of contamination are to be seen as safe, since the building works will disperse dust that may represent a radiological hazard through inhalation or other routes. The general conclusions of these analyses and their assessment has been that there is no safety issue as radiation levels are from natural background and that no fission product or activation radionuclides from the existing reactors (e.g. Caesium-137, Cobalt-60) have been found.

We have independently examined the data to see if there were any radiological safety issues. There are.

2. Enriched uranium and gamma spectroscopy

We have concentrated on the gamma spectroscopy data presented in the document *AMEC Phase 2 Supplementary Investigation of Potential Radiological Contamination EDF Access Appendix C Soil Sampling Data and Comparison with Background Values- December 2008 AMEC 15011/TR/00091*

We have also employed maps of the locations of the samples given in *Hinkley Point C Preliminary Works, Site Preparation Works* Figures 16-7, 8a, 8b and 9. Gamma spectra data can be used (with some caveats, see below) to determine the activity concentrations of U-235 and U-238.

These are the two isotopes of interest in determining if uranium in a sample is natural or from a man-made source, namely U-238 and U-235. The natural isotope activity ratio is 21.3. That is, U-235, the fissile component used in nuclear reactors is present in natural uranium, from a mine, from the environment with 1/21.3 times the activity of U-238. The atomic ratio is 137.88, and this is what is measured when samples are analysed by mass spectrometry. But with gamma spectrometry, the ratio should be 21.3. If it is less, then there is a proportion of enriched uranium in the sample, and this has to be man-made. Enriched Uranium (which is more radioactive than natural uranium) does not exist in nature.

There is, however, a problem in that U-238 is not a gamma emitter, and we have to rely on the gamma activity of its immediate daughter decay product Thorium-234 to signal the activity of U-238. Whilst this will give an accurate value for U-238 it can give an incorrect result for the U238/U235 ratio since Uranium is more soluble than Thorium, leading to a loss of U-235 relative to Th-234. But such a process would signal Depleted Uranium as the ratio would be too high, greater than 21.3. So if we are finding Enriched Uranium from a man-made source, using gamma spectral data, it is certainly there. And it is.

3. Enriched Uranium in the soil and the natural background

It is a safety issue of remediation that any analysis with regard to remediation must begin with determining the natural background radiation levels in terms of radionuclide contamination and in terms of gamma radiation exposure rates. We used

the data given in the soil sampling gamma spectra to calculate the uranium enrichment activity ratios of the samples and also the total uranium activity levels.
The activity (A) ratios are simply:

$$\mathbf{R} = \mathbf{A}(\text{Th-234})/\mathbf{A}(\text{U-235})$$

The total activity of Uranium-238 in the samples we have assessed as:

$$\mathbf{A}(\text{Utotal}) = \mathbf{A}(\text{U-235})*21.3$$

This is not quite correct since it depends on the degree of enrichment; the true value might be 15% less on average since the overall mean enrichment ratio is about 17.5. Note that, as the enrichment ratio **R** falls, there is more of the nuclear reactor fuel contamination. The results are given in Table 1. A number of conclusions can be drawn:

1. The uranium is not natural in most of the samples: it is mostly man-made enriched uranium, presumably from uranium reactor fuel from the Hinkley Point reactors.
2. Samples were taken from different depths. The trend with depth shows that the surface samples contain significantly more enriched uranium, suggesting that the contamination is from airborne precipitation.
3. The trend with depth also shows that the activity concentration is highest at the surface, and about double the activity concentration in the deep samples which appear to be natural uranium.
4. The trend analysis allows the calculation of the excess man-made uranium to be approximately 40Bq/kg that, in turn, enables an assessment of the quantity of enriched uranium contamination in the 2km^2 area alone as 10 tonnes.
5. There is a non-significant correlation between uranium activity concentration and distance from the sea suggesting that, at least, part of the contamination is due to sea-to-land transfer; however, more measurements must be made to further examine this point.

4. The uranium trends with sample depth

Most interesting in establishing the origin of the enriched uranium is the correlation between the activity ratio of uranium and mean depth of the sample. This is plotted in Fig 1. The result shows a statistically significant linear correlation:

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*** Linear Model ***

Call: lm(formula = Uratio ~ depth, data = hinkleyedf2, na.action =
na.exclude)
Residuals:
    Min     1Q   Median    3Q   Max
 -5.557 -1.554 0.007509 1.438 6.082

Coefficients:
              Value Std. Error t value Pr(>|t|)
(Intercept) 16.2886  0.9270    17.5709  0.0000
      depth  1.7296  0.5868     2.9473  0.0065

Residual standard error: 2.896 on 27 degrees of freedom
Multiple R-Squared: 0.2434
F-statistic: 8.687 on 1 and 27 degrees of freedom, the p-value is 0.006
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Table 1 Hinkley EDF

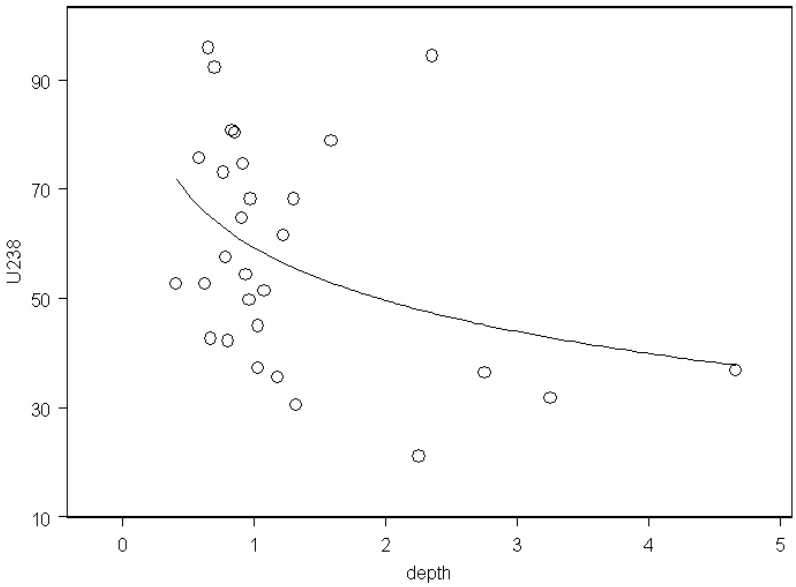
sample	depth	seadist	U235	Th234	th234/u235	U238calc	note

the 1m top layer of the roughly 2km^2 area defined by the survey. Of course, this will not be constrained to this area. Note the trend with depth given in Fig 4 shows a remarkably steep increase in uranium concentration between 0.4 and 1.5 metres. Linear extrapolation to the surface would suggest a surface activity of 150Bq/kg or greater. The AMEC report states:

P10
Samples were excluded if they were taken in the first 0.2 m below ground level as material from this region had been previously sampled. Samples submitted for analysis were taken from depths ranging from 0.26 m to 4 m bgl.

However, analytical results for this surface layer are not presented anywhere in any of the documents. And this is perhaps unsurprising, though unacceptable in an environmental impact report. Given the trend of U235 enrichment we might expect the surface 20cm to be highly contaminated with enriched atomic reactor fuel residues.

Fig 4. Uranium total activity concentration (modelled as U235 * 21.3) by depth of sample (exponential fit). Linear correlation statistically significant at p<.05 Note that if two outliers are removed there is a remarkably steep concentration gradient down to 1.5metres




```
Call: lm(formula = U238 ~ depth, data = hinkleyedf2, na.action = na.exclude)
Residuals:
    Min     1Q Median   3Q   Max
 -29.12 -12.74 -4.763 11.7 44.98

Coefficients:
               Value Std. Error  t value Pr(>|t|)
(Intercept)  68.6785   6.2544    10.9808   0.0000
      depth  -8.2117   3.9593    -2.0740   0.0477

Residual standard error: 19.54 on 27 degrees of freedom
Multiple R-Squared: 0.1374
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F-statistic: 4.302 on 1 and 27 degrees of freedom, the p-value is 0.04774
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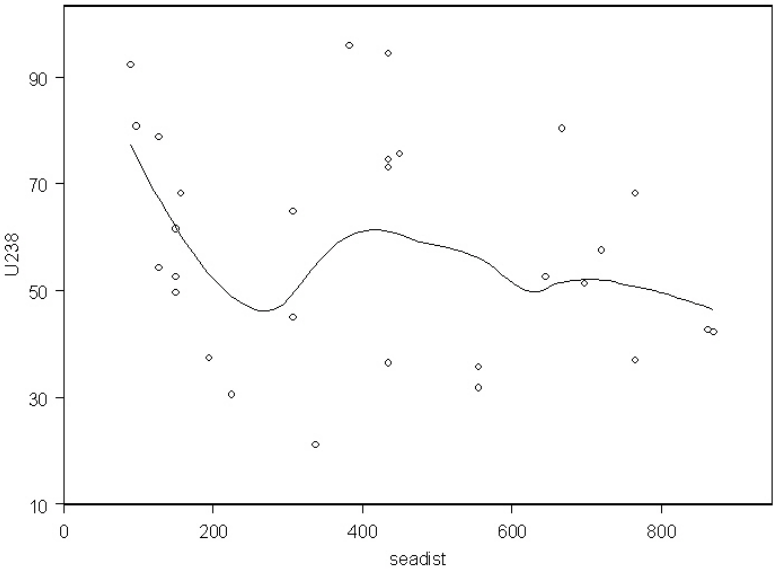
6.2 decreasing concentration with sea distance

There appears to be a decreasing concentration with distance from the sea, though this is not linearly statistically significant and varies with the depth. There does seem to be a statistically significant sea coast local increase in the 300m distance band as is shown by the LOESS plot in Fig 5.

Fig 5. Total uranium activity concentration by distance from the sea (modelled as U235*21.3) LOESS fit



6.3 trend with radial distance from the nearest nuclear reactor

There does not appear to be any trend with distance from the nearest nuclear reactor (graph not shown).

6.4 U-238 concentrations and caveats

In the previous analyses of trends, the variation of Uranium activity concentration with depth and distance from sea were modelled as a function of U-235 activity. If they are modelled for U-238 using Th-234 as the measure, the trend with depth is not statistically significant at the p = 0.05 level. Nevertheless, the total U-238 concentration mean, measured as Th-234 is 50Bq/kg (compared with 58Bq/kg if the U235*21.3 is used), a reduction of 15% as expected (see Section 3 above). Clearly more data is needed and preferably measurements using ICPMS as well as gamma spectrometry.

7. The origin of the enriched Uranium and its effects

Since there is an increase in activity concentration and enrichment near the surface, the material probably originates from the air. All nuclear power stations release airborne particulates and their contribution to doses has been tabulated in UNSCEAR 2000 (Annex C, Table 34), where Hinkley Point's releases are given by year from 1990-1997. This is shown in Table 2. It is of interest that the UNSCEAR 2000 table shows that Hinkley Point A and B consistently gave the greatest particulate releases of all the gas-cooled reactors tabulated up to 1994 after which time the levels reduced in line with other reactors in France, Spain and Japan. Hinkley B, A-B released on average 0.4GBq (400,000,000Bq per year) of particulate radioactivity in this period compared with 0.0033GBq from Hunterston and 0.082 from Wylfa. Another "dirty" particulate-releasing reactor is Trawsfynydd in Wales that released 0.28GBq in 1990, the last year it operated. But it is unclear how these values were obtained or whether they will have included the uranium component. It is of interest that both Trawsfynydd and Hinkley Point are associated with increased rates of breast cancer and other cancers in downwinders (Busby et al 2006, Busby et al 2000, 2007). However, the airborne particulate quantities tabulated do not account for the levels of enriched uranium found in the EDF data. There is also the significant trend in these data with the distance from the sea coast which suggests that at least part of the contamination is from sea-to-land transfer of material released to the sea from the site, a theory advanced elsewhere to explain increases in cancer in coastal communities of the Irish Sea, the Baltic sea and the peculiar increased cancer and infant death rates in Burnham-on-Sea, the town downwind of Hinkley Point which has been studied since 2000 (Busby 2002, 2008, Busby 2006 for a review of all the studies carried out by Green Audit).

Table 2 Reported releases (GBq) from Hinkley Point to sea as liquid radioactive effluents and as radioactive particulates by year from 1990-1997 as shown in Table 34 and 36 of UNSCEAR 2000 Annex C

Particles

Site	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
A	0.3	0.23	0.15	0.23	0.23	0.16	0.077	0.17
B, A-B	0.57	0.46	0.32	0.40	0.31	0.08	0.077	0.075

Liquid effluents excluding tritium

Site	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
A	751	729	610	686	724	981	570	707
B, A-B	38	27	16	15	21	17	9	15

There are significant liquid effluents: Hinkley Point is tabulated in UNSCEAR 2000 as releasing very significant amounts of total radioactivity to the sea. From UNSCEAR 2000 Table 36, between 1990 and 1997, Hinkley Point is recorded as releasing 5916GBq (5.9 TBq) of activity to the sea local to the plant in an area of low tidal energy where it was likely to bind to sediment and become concentrated. This is about 25% of the 1957 Windscale fire releases of about 25 TBq of Caesium-137 and Strontium-90 combined but to a much smaller area. If we employ the total period fom commission in 1976 to 1997, 22 years, and assume the same rate of release the total quantity becomes 14.5TBq. We do not know if uranium releases are included in these figures.

This analysis raises the possibility that many of the health effects found near nuclear sites (childhood leukaemia, breast cancer, infant mortality) may be in part at least driven by the inhalation of Enriched Uranium releases from the stations either directly from particulates or indirectly via sea-to-land transfer of contaminated sediment. Uranium is a missing isotope in measurements near nuclear sites; there is little data. In dismissing the Sellafield child leukaemia cluster as caused by radiation from the plant, both NRPB and COMARE argued that doses from natural nuclides were greater than from plutonium from Sellafield (see Busby 2006 for a discussion and references). However, uranium exposures in these areas are not natural: they are anthropogenically enhanced (TENORM) and recent studies in Iraq and elsewhere (see ECRR2010, Busby 2010), including theoretical studies (Busby and Schnug 2008, Busby 2005) have shown that Uranium, especially particulate Uranium, carries an anomalous enhancement of risk (Busby 2010, ECRR2010, www.euradcom.org). The various official analyses (RIFE, CEFAS) concentrate on measuring tiny quantities of exotic radionuclides in environmental samples but uranium is not usually measured.

8. Conclusions

This has been a very interesting study and has provided important information. In the last 10 years there has been increasing interest in the anomalous health effects of uranium, fuelled by research into uranium weapons. From both epidemiological and theoretical work it has become clear that uranium exposure through inhalation of concentrated or pure uranium particles results in high risk of genetic damage, cancer and leukaemia/lymphoma at very low doses, conventionally expressed (see ECRR2010, or references at www.euradcom.org). Most recently, alarming increases in breast cancer, leukaemia, childhood cancer and congenital malformation/infant mortality increases were found in Fallujah, Iraq, a city where uranium weapons were employed and uranium particles will have been inhaled (Busby et al 2010). Unpublished results of analysis of soil from Fallujah have shown the presence of enriched uranium.

The analysis presented here suggests that enriched uranium, from a different source, the Hinkley Point reactors, may have contributed to the increased levels of cancer downwind of the plant. It has certainly contaminated the area where it is proposed to site a new reactor and where there will be substantial building works involving digging up and moving large quantities of soil contaminated with this material. This will pose a public health hazard to workers and to those downwind of the building works.

In addition, these results show quite clearly that the radiation levels and radionuclides present at this site are not “background radiation” and cannot be assumed to be any sort of background for legal purposes. The quantity of new uranium present on the site alone may be calculated at roughly 10 tonnes and all of this material is from the Hinkley Point historic operation. Whether the material is derived from the stacks as particulate releases or whether it is sea-to-land transfer of liquid discharge material remains to be established; either way it draws attention to a release of radioactivity that has been overlooked. In view of the recent evidence of increased levels of child leukemia (and other cancers) in those living near such plants, the further investigation of the dispersion of uranium from such plants would seem to be an urgent requirement. CEFAS has been asked to measure uranium isotopes in samples near nuclear sites for some years now: nothing has been done. Enormous care is taken to measure obscure fission products in samples, and to present the results in the annual RIFE reports but no effort is made to examine uranium, which is somehow

assumed to be irrelevant as it is somehow natural. It is not natural near nuclear sites, it is properly termed TENORM, Technologically Enhanced Natural Radioactive Substances, and it is certainly not benign.

7. Recommendations

1. All building work and site preparation should be halted immediately.
2. This site and others surrounding the reactors should be gridded and a sufficient number of samples taken from the surface and a series of depths at distances from the sea. These samples from GIS recorded locations should be examined by gamma spectroscopy and by ICPMS Mass spectrometry, preferably by an independent laboratory or laboratories.
3. Gamma exposure rate measurements at 1m should be recorded for the same locations. According to the US NCRP Report No 84 Table 5.1 the gamma dose rate over well-mixed soil with Uranium at a concentration of 40Bq/kg is 160microSieverts per annum and this already exceeds the Euratom threshold for a single source exposure without invoking inhaled particles. It is estimated from the gamma spectra that the dose rate over the proposed area will be significantly higher than the 40- 50microSieverts measured for the area by NRPB in their published gamma records for England.
4. The normal operation of nuclear plants should be investigated with regard to releases of respirable enriched uranium to the environment and the possibility that this is one source of increased risk of leukaemia/lymphoma and cancer in local communities. High Volume air samplers should be located near nuclear plants and uranium and uranium isotope rations measured over a representative period.
5. Access to the site and to sampling from the site and the beach should be given for independent examination and analysis of the environment.

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Summary, implications and notes for non-scientists

In the UK, before permission is given for a project which may have health implications for workers and local members of the public, an environmental impact analysis must be provided. This is particularly relevant for a process which involves potential exposure to radiation since radiation is invisible to ordinary people and causes cancer and other illnesses, usually long after the exposures and therefore difficult to connect causally. The measurement of radiation and the substances which are radioactive, termed radionuclides, and the assessment of radiation risk, is a matter for experts and complex, sophisticated and expensive equipment. The proposal to build a new nuclear reactor at the Hinkley Point site has had, therefore, to involve the developer, EDF Energy, in creating an environmental impact report. Hinkley Point has been a nuclear energy generating site since the late 1960s, initially with carbon dioxide cooled MAGNOX reactors, the A reactor more recently with AGR reactors the B site which employs enriched uranium as a fuel. There have been health questions about Hinkley Point's operation since the 1980s, first with a report of excess child leukaemia (Cameron Bowie) and then later reports of increased breast and others cancers in the coastal town downwind of the plant, Burnham on Sea. The increased risk of cancer in Burnham on Sea and increased infant mortality in the town, have been conceded by the authorities, but the causal link with radioactivity has been consistently denied. This denial, like the other denials of radiological causes of increased cancer and child leukemia risk near nuclear plants, has been entirely based on deductive science. Since the 1984 Black enquiry on the Sellafield child leukemia cluster it has been argued that the risk model of the International Commission on Radiological Protection ICRP which is based on high acute doses to Hiroshima Survivors, does not predict the cancers because the doses from these plants are too low. However, this ICRP model is based on external radiation, gamma rays and is increasingly conceded to be wrong for internal radionuclides, not least by the editor of the latest ICRP report, Jack Valentin. For such exposures to particulates and nuclides that bind chemically to the DNA, the concept of dose is now universally conceded to be invalid. Independent scientists from many countries formed a grouping 1998, the European Committee on Radiation Risk (ECRR) to develop a risk model which predicts and explains the effects of internal radionuclide exposure, and this was published in 2003 and updated in 2010 (www.euradcom.org). It has explained all the relevant observations of cancer in exposed populations including many which it predicted and which followed its publication.

It is the internal contamination of people local to nuclear plants that is seen by the ECRR to be the cause of the increased levels of cancer and leukaemia in children. And one route which has been established is the inhalation of contaminated aerosol dust generated by sea to land transfer of contaminated sediment. Sea coast effects have been discovered in Wales, Ireland, Sweden and Finland in populations living near contaminated coastal intertidal sediment. A large joint Swedish/ Latvian EU funded study of cancer near the contaminated Baltic sea was proposed in 2010 and is awaiting consideration by the EU Interreg IV framework.

One radionuclide that is now known to be far more hazardous that the current ICRP risk model predicts is Uranium. Research carried out on the effects of Depleted Uranium and Uranium weapons has shown that the inhalation of highly concentrated Uranium particles carries an enormously enhanced cancer and infant death risk compared with its modelling by the ICRP. But curiously Uranium is not measured

near nuclear sites despite the obvious fact that it is the main substance involved in nuclear energy generation. This is why the EDF Energy Environmental Impact Statement and its associated documents are such an important resource: they show for the first time the presence of widespread enriched uranium contamination near a nuclear reactor

Uranium has two relevant isotopes for this analysis: U238 and U235. It is the U235 which is fissionable and is used in bombs and nuclear reactors. U235 is not easy to measure in trace quantities and in natural uranium, the amount of U235 present, is about 1/140th of the total uranium. The best method for analysis has only recently been developed: it is Inductively Coupled Plasma Mass Spectrometry, ICPMS. This separates the atoms by virtue of their mass and counts them. The method used by AMEC for EDF was much less sensitive. It is gamma spectrometry. But U-238, the parent, is not a gamma emitter and cannot be seen by gamma spectrometry. However, it decays to a daughter nuclide, Thorium 234, which has a short half life, 24 days, and since the U-238 half life is 4.7 billion years, the ratio of U-238 to Th-234 is 1:1. They are said to be in secular equilibrium. Th-234 is a weak gamma emitter and can be detected. 3% of it decays with energies at 924 and 928 keV, two gamma peaks which are easy to see, though weak since they represent only 3% of the decays. The other nuclide, U-235, is a gamma emitter with a 53% peak at 186keV. Unfortunately, this is also the decay peak for Radium-226 which is generally present in the environment. Nevertheless it is possible to disentangle the two components using other Radium-226 daughter peaks. So, with various caveats, it is possible to determine if a sample is enriched with U235. And what we see in the EDF data is that the contamination of the field near the Hinkley Point reactors consists of enriched uranium which is most concentrated and most enriched near the surface. It also seems most concentrated near the sea.

In addition, and this is quite simple and easy to see for a non-expert, the activity, (concentration) of uranium in the EDF site is too high; helpfully, the Environment Agency had produced a report of background Uranium concentrations in England and Wales, and the levels at Hinkley Point are shown on a map, which is reproduced in this paper. They are less than half the levels at the EDF site reported by AMEC.

To summarise:

- there is too much uranium,
- the uranium is enriched,
- it is on the surface and
- it is close to the sea.

The most plausible explanation is that this plant, Hinkley Point, has been releasing enriched Uranium to the sea and/or to the air. And this has been driven ashore on the coast. Therefore anyone living on the coast or near the plant will have inhaled this material.

The releases of radionuclides from nuclear plants is not a new discovery: it is a well documented phenomenon. The 2000 report of the United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR lists releases from Hinkley Point to the sea and to the air. Hinkley Point was relatively dirty according to the UNSCEAR data. What we see from the EDF data, for the first time, is how these releases do not get harmlessly blown away in the air, or diluted in the sea and disappear, but are resuspended and become available to coastal populations as an inhalation exposure. Such exposures to these resuspended particles, are now shown to

be real for the first time near a nuclear site. These will have resulted in inhalation and translocation from the lungs to the lymphatic system and the blood. This process will affect the lungs, the female breast (highly lymphatic) and the lymph and blood systems, causing high radiation doses to local tissue. And increases in leukaemia, lymphoma, breast and lung cancers are seen in coastal populations at a higher rate than inland population is areas where there are nuclear sites or contamination. In the COMARE and NRPB reports on the famous Sellafield child leukaemia cluster, doses were greatest to the tracheobronchial lymph nodes which drain the lung. But the plant was exonerated on the basis that the doses from natural radionuclides were greatest, greater than the plutonium that had been suggested as the cause. But what if it wasn't the plutonium? What if it was the uranium, the enriched uranium? COMARE were asked for the calculations. They wrote that the work was done by NRPB. NRPB were asked for the calculations, but refused to release them.

At the EDF site, the gamma data is incomplete. Surface samples are not reported. Why? The trends shown in this paper suggest that the surface layer would have been too radioactive to report. If this is so, the gamma exposure rate is also high: this also is not reported. Where is the uranium from? The best suggestion, from a study from STUK in Finland and other sources confirms the earlier conclusion. One source is that the uranium fuel particles are from corroded or split fuel canisters. UNSCEAR 2000 concedes that fuel particles containing very hot short lived isotopes do escape from all nuclear reactors, and tabulate the release data provided by the individual plants worldwide. But this data is provided by the operators themselves, and there are many instances of their being caught concealing releases. Uranium is the fuel in nuclear reactors and it is loaded into the reactors where fission causes it to become extremely hot. In stations like Hinkley Point a stream of carbon dioxide carries away the heat, but if the fuel elements become split or corroded, radioactive particles of enriched uranium are also carried away, contaminated with a range of very hot short lived radionuclides. The burnt fuel cans are left in cooling ponds.

This is a very significant discovery. In the *gung ho* political environment of nuclear new build, it must not be ignored. The contamination of local areas by enriched uranium fuel must be investigated; a start is to obtain the surface data omitted from the EDF report, and a formal Freedom of Information Act Request has been sent to EDF for this.