**TOWN AND COUNTRY PLANNING (APPEALS) (SCOTLAND) REGULATIONS 2013**

**APPEAL UNDER SECTION 47(2) OF THE TOWN AND COUNTRY PLANNING (SCOTLAND) ACT 1997 BY DART ENERGY (FORTH VALLEY) LTD CONCERNING COAL BED METHANE PRODUCTION, INCLUDING DRILLING, WELL SITE ESTABLISHMENT AT 14 LOCATIONS AND ASSOCIATED INFRASTRUCTURE AT LETHAM MOSS, FALKIRK, AND POWDRAKE ROAD, NEAR AIRTH, PLEAN**

**(REFERENCES PPA-240-2032 AND PPA-390-2029)**

**PRECOGNITION BY Dr Ian Fairlie**
**ON BEHALF OF**
**CONCERNED COMMUNITIES OF FALKIRK**
**(AND SUPPORTERS)**

## Summary

All fossil fuels extractive activities, including coal bed methane (CBM) extraction, involve the release of radioactive gases and liquids. The released nuclides, radium-226 and radon-222 in particular, are mostly highly radiotoxic. Data supplied in Dart Energy's Supporting Information on discharges of radioactive waters, sludges and scales indicate [*word deleted*] concentrations of radium-226, radium-228 and lead-210 in the produced water of Dart's pilot operations. [*sentence deleted*] Dart Energy has applied to SEPA for statutory Authorisations for these discharges and disposals. SEPA should be asked whether it intends to grant such Authorisations and, if so, under what conditions.

Dart Energy has not considered the health implications of radon gas emissions in its documentation. [*sentence deleted*]

Any decision by the Reporters should be dependent on [*4 words deleted*] the terms of any proposed RSA Authorisation by SEPA; and assurances by Dart Energy on pre- and post-operational radon gas measurements at its Airth sites, among other matters.

Dart Energy's CBM extraction proposals would result in the discharge of ~ 1.7 GBq (billion becquerels) of radioactivity in produced water each year to the river Forth and the transportation of ~ 0.2 GBq of radioactivity in sludge to licensed radioactive waste dump sites. These are relatively large amounts of radioactivity and, on balance, and in line with the Precautionary Principle, I caution against Planning Permission being granted to the CBM extraction proposals at Airth.

## Introduction

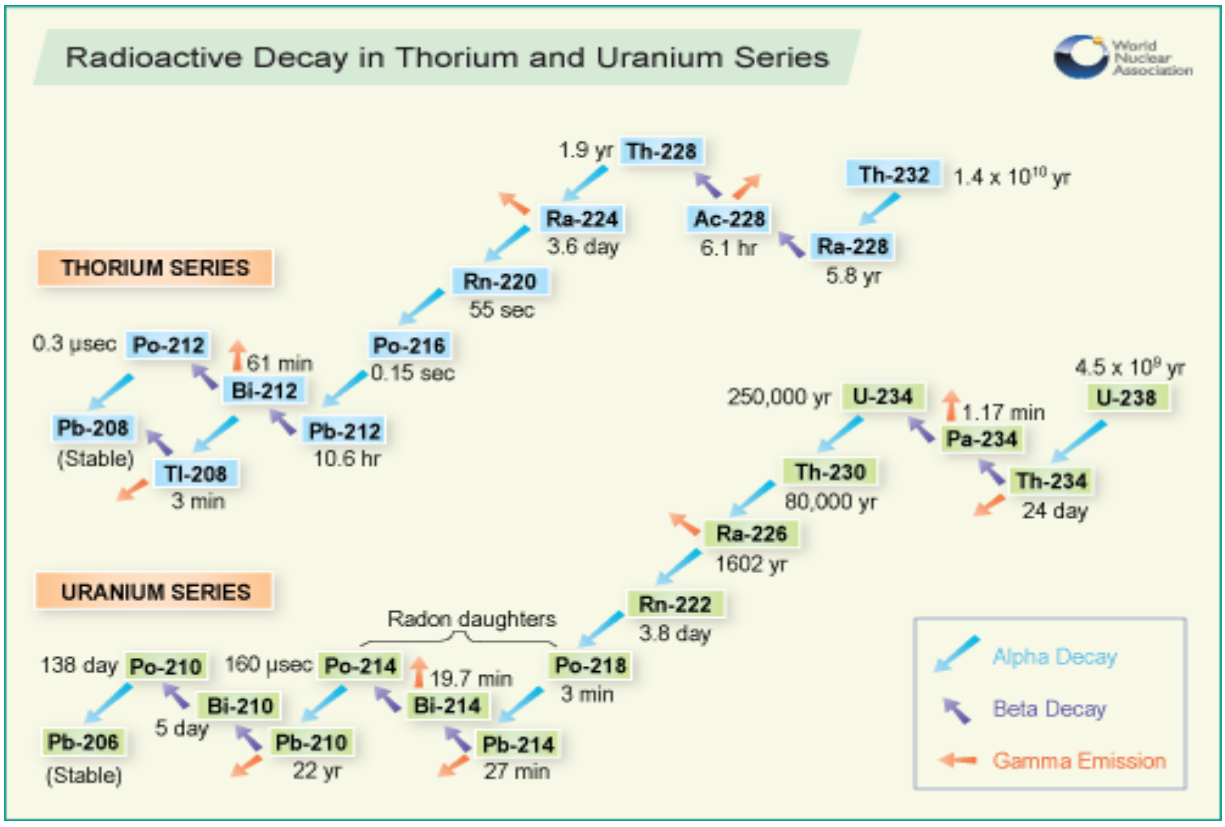
1. I am Dr Ian Fairlie, an independent consultant on radioactivity in the environment. I have degrees in chemistry and radiation biology and my doctoral studies at the Imperial College of Science Technology and Medicine and at Princeton University examined nuclear waste technologies. I have been employed by, and acted as consultant to, several UK Government Departments, the European Parliament, WHO, environment NGOs, local authority associations and SEPA. I am a member of the Society for Radiological Protection. I have written many scientific articles on the effects of radionuclides and on radiation in general: a full list of my published articles is available at http://www.ianfairlie.org/publications/ Most recently, I was scientific Secretary to the Government's Committee Examining Radiation Risks of Internal Emitters (www.cerrie.org).

## Evidence

### A. Radioactivity in the Earth

2. Underground rock and mineral strata throughout the world contain radioactive matter in highly variable concentrations. This is often termed Naturally Occurring Radioactive Material, whose acronym is NORM. The average radioactivity[1] of the Earth's crust is about 1,400 becquerels per kg and mainly consists of the primordial nuclides uranium-238 (U-238), thorium-232 (Th-232) and potassium-40 (K-40) which have very long half lives near to or exceeding the age of the Earth. A becquerel (Bq) is a unit of radioactivity equivalent to one nuclear disintegration per second.

3. The concentration of K-40 in the Earth's crust averages 370 becquerels per kg (Bq/kg) with a typical range of 100–700 Bq/kg. U-238 and Th-232 average about 25 Bq/kg each with typical ranges of 7–50 Bq. Some soils vary considerably from these ranges[2]. Importantly, uranium-238 and thorium-232 co-exist with their radioactive progenies – see decay chart below – and the concentrations of these 25 nuclides must be included.




4. As regards radiation exposures, the decay daughters of U-238 and Th-232 are the most important nuclides for the following reasons.

- First, in undisturbed soils/rock strata these nuclides exist in serial equilibria, so their concentrations have to be added together to obtain the total concentration of radioactivity in soils/strata. This means that to obtain the total radioactivity from U-238 + daughters one multiplies the measured U-238 concentration by a factor of 14. Similarly for Th-232 + daughters, one multiplies its concentration by a factor of 10. (IAEA source[3] for these factors).

[1] CCoF 283: IAEA (2003) Extent of Environmental Contamination by Naturally Occurring Radioactive Material (NORM) and Technological Options for Mitigation, Technical Reports Series No. 419, STI/DOC/010/419. International Atomic Energy Agency. http://www-pub.iaea.org/MTCD/publications/PDF/TRS419_web.pdf.

[2] CCoF 284: IAEA (2000) Generic Procedures for Assessment and Response during a Radiological Emergency *IAEA TECDOC Series No. 1162* IAEA Vienna. http://www-pub.iaea.org/MTCD/publications/PubDetails.asp?pubId=5926

[3] CCoF 283: IAEA (2003) Extent of Environmental Contamination by Naturally Occurring Radioactive Material (NORM) and Technological Options for Mitigation. Technical Reports Series No. 419, STI/DOC/010/419 (ISBN:

- Second, many oil/gas well analyses indicate that it is not uranium and thorium but their daughters Ra-226, Ra-224, Ra-228 and Pb-210 which are highly mobilized from rock formations, mainly in the water produced during oil and gas extraction. These isotopes and their radioactive progeny then precipitate out of solution, as radioactive sulphate and carbonate deposits in scale or sludge in pipes, pumps and related equipment. This often leads to high levels of radioactivity in oil/gas extraction equipment: for this reason pipe workers are classified as radiation workers due to the occupational doses they receive.

- Third, radon-222 and radon-220 are gases ie highly mobile in the environment. These gases travel in gas pipes and themselves decay to stable lead and longer-lived radioactive lead isotope Pb-210 which has a half-life of 22 years. This also builds up in thin layers in gas extraction equipment. These gases are also readily soluble in the water extracted from gas wells.

- Fourth, these nuclides are highly radiotoxic. For example, polonium-210 found in the U-238 chain was the radionuclide used in the death of the Russian dissident Alexander Litvinenko in London in 2006. Although no useful hazard table of radionuclides exists, the standard US textbook "Radiochemistry and Nuclear Chemistry" by Choppin et al[4] states (page 108) "*Since Rn and Ra are among the most radio-toxic substances existing, causing lung and bone cancer at relatively low concentrations…special attention must be devoted to their appearance in nature*."

5. The average exhalation rate of radon from the ground is 0.005 to 0.05 Bq/m$^2$s, leading to a near ground level radon concentration of 1 - 10 Bq/m$^3$, although this varies widely with ground conditions. Representative values for UK are ~3 Bq/m$^3$. Rn concentrations in air above ground depend very much on temperature and wind conditions[5].

## B. Radioactivity in Coal Beds

6. Most coal beds contain uranium and thorium, their decay products and K-40. Their concentrations are generally about the same as in adjacent rocks or strata which vary according to region and geology. Table 1 presents some typical UK values[6], though coal seams in some areas can contain higher levels of radioactivity.

Table 1. Radionuclide activities in UK coal (Bq/kg)

| U-238 alone | Ra-226 | Th-232 alone | K-40 |
|---|---|---|---|
| 7-19 | 8-22 | 7-19 | 55-314 |

7. Radon gas also exists in underground coal mines and levels can be quite high. Denman et al (2003) (CCoF 163) found radon levels ranging from 60,000 to 700,000 Bq per m$^3$ in British coal mines with an average of ~400,000 Bq/m$^3$. For comparison, the recommended action level for radon remediation in homes is 200 Bq/m$^3$. Where levels higher than are detected, action should be taken, eg sump pumps installed.

## C. Radioactivity in Gas Wells

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9201125038) International Atomic Energy Agency, pp 24, 30. http://www-pub.iaea.org/MTCD/publications/PDF/TRS419_web.pdf

[4] CCoF 285: Choppin GR et al. Radiochemistry and Nuclear Chemistry. Butterworth–Heinemann Ltd. Oxford 1995.

[5] CCoF 285: Choppin GR et al. Radiochemistry and Nuclear Chemistry. Butterworth–Heinemann Ltd. Oxford 1995.

[6] CCoF 283: IAEA (2003) IAEA Tech Report 419, p 24.International Atomic Energy Agency. Extent of Environmental Contamination by Naturally Occurring Radioactive Material (NORM) and Technological Options for Mitigation, Technical Reports Series No. 419, STI/DOC/010/419 (ISBN: 9201125038). http://www-pub.iaea.org/MTCD/publications/PDF/TRS419_web.pdf.

8. In addition, radioactivity exists in gas and oil wells including fracking wells[7]. Table 2 indicates typical nuclide concentrations in various materials found in gas and oil wells across the world[8]. Comparable data for the UK do not appear to exist presumably as there are few such wells on UK land.

Table 2. Radioactivity levels in oil and gas wells

| **Radionuclide** | **Natural gas Bq/m$^3$** | **Produced water Bq/L** | **Hard scale Bq/kg** | **Sludge Bq/kg** |
|---|---|---|---|---|
| U-238 | | trace | 1 - 500 | 5 - 10 |
| Ra-226 | | 0.002 - 1200 | 100 - 15 million | 50 - 800,000 |
| Po-210 | 0.002 - 0.08 | | 20 - 1500 | 4 - 160,000 |
| Pb-210 | 0.005 - 0.02 | 0.05 - 190 | 20 - 75,000 | 10 - 1.3 million |
| Rn-222 | 5 - 200,000 | | | |
| Th-232 | | trace | 1 - 2 | 2 - 10 |
| Ra-228 | | 0.3 - 180 | 50 - 2.8 million | 500 - 50,000 |
| Ra-224 | | 0.05 - 40 | | |

9. From theoretical considerations, radioactive gas releases from CBM wells are expected to be lower than those from oil/gas fracking wells. This is because radon gas is suddenly released in relatively large quantities by fracking and will not be in equilibrium. In layman's terms, during fracking, released radon will not have had time to decay before it is extracted. (This mainly concerns Rn-222 with a half life of 3.8 days.) With CBM extraction, the radon in trapped coal seams and pores will be in equilibrium, ie it will be in lower concentrations. Nevertheless, some increases in radon levels are expected to occur near CBM extraction wells: a recent study (CCoF 76) has revealed a statistically significant relationship between radon-222 concentrations in air and the number of CBM gas wells at gas extraction sites in Australia.

10. The Tait et al study (CCoF 76) proposed that raised radon levels are due, not only to the gas extraction infrastructure, but also to the depressurisation (by groundwater extraction) of coal bed strata. Both processes lead to widespread diffuse soil emissions of radon. Conceptually, this is similar to the large increases in radon emissions which precede earthquakes: the radon increases are caused by increased stresses which alter sediment pore spaces and open and close cracks. This means that radioactive gas emissions from the proposed CBM extraction at Airth should be addressed and their potential health effects considered. This has not been done to date, as far as can be ascertained.

[*Section D – paragraphs 11 to 13 deleted*]

## E. Dart Energy: Proposals for radioactive waste at Airth

14. As stated in Dart Energy's Supporting Information document (DE 60) radioactive wastes will be generated in produced waters, in sludges and in pipeline scales. In addition, radioactive radon gas (Rn-220 and Rn-222) is likely to be released. These radioactive gases and liquids will be released in variable concentrations, but they will result in some level of radioactive contamination of nearby outfall streams, mudflats and benthic organisms. The emissions and discharges could result in health effects in local populations and workers. The important questions are (a) how much radioactivity will be released to the environment near Airth, and (b) in what concentrations. For these, we now turn to the situation at Airth.

(a) Airth - Radioactive gas emissions

[7] CCoF 193: Brown VJ (2014) Radionuclides in Fracking Wastewater. Environmental Health Perspectives, volume 122 number 2, February 2014 pp A50-A55. http://ehp.niehs.nih.gov/122-a50/

[8] CCoF 286: IAEA 2003, Safety Report Series 34.International Atomic Energy Agency, 2003, Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry, Safety Report Series No. 419, STI/PUB/1171 http://www-pub.iaea.org/MTCD/publications/PDF/TRS419_web.pdf.

15. As stated above, it appears that no radon gas concentrations have been measured near the 22 proposed CBM sites at Airth. However a recent report (CCoF 133)[9] from the Government's advisory body Public Health England, has recommended (page 33) that "*Baseline environmental monitoring is needed to facilitate the assessment of the impact of shale gas extraction on the environment and public health. There should also be consideration of the development of emission inventories as part of the regulatory regime."*

16. Accordingly we recommend that Dart Energy should determine Rn-222 and Rn-220 concentrations at these sites before any extraction occurs to provide pre-production baseline levels. In addition, Dart Energy should draw up and maintain estimated inventories of these radioactive gas emissions.

(b) Airth –Radioactivity in produced water
[*Paragraphs 17-19 deleted*]

20. From para 3.2.1 in its Supporting Information document (DE 60), "*Dart Energy predicts a peak generation of produced water of 774 cubic metres (m3) per day once all the production wells are in operation. The volume of produced water pumped out of the boreholes is expected to decrease as the CBM field matures."* It is noted in passing that this is a very large volume of produced water amounting to 774,000 litres per day or 280 million litres per year.

21. From its Supporting Information document (DE 60), Dart Energy (see table 3) is proposing to discharge a total of 1.68 GBq[10] (billion becquerels) per year via produced water in outflow streams and pipelines into the river Forth. In my view, this is a very large amount of radioactivity, equivalent to about 4.6 MBq (million becquerels) per day. This would result in the Forth mudflats near Airth, and its flora and fauna, being exposed to increased levels of radioactivity. Such levels of radioactive contamination would be a high price to pay for the methane gas produced. My initial responses would be…is it really necessary to do this? Are there alternative ways of satisfying our energy needs? Human health aspects are considered below.

(c) Airth – Radioactivity in sludges and scales
22. Radioactive sludges and scales will be produced from the proposed operations at Airth. From its Supporting Information document (DE 60), Dart Energy (see table 4) is proposing to dump 0.22 GBq of radioactive wastes per year in 334 tonnes of sludge at licensed radioactive waste landfill sites. My reaction to this proposal would be to seek the views of SEPA on its viability and practicability.

23. As regards radioactive scale, para 4.3.4 of Dart's Supporting Information document (DE 60), states *"Dart Energy proposes to secure the services of a licensed contractor for the removal and disposal of scale from pipework and other plant equipment at appropriate time intervals for sentencing to a suitable controlled burial/ landfill site. It is not anticipated that this waste will be accumulated or kept on site".* In my view, some estimates should be made of the amounts of radioactivity involved and the likely levels of radiation doses to workers, visitors and nearby people from this scale.

(d) Statutory requirements
24. In its Regulatory Guidance on Coal Bed Methane and Shale Gas (Version 12.11,15. para 43) (CCoF 60) SEPA stated *"Based on experience, we are adopting a prudent position that unless the operator can demonstrate by measurements that the concentrations of NORM are below the threshold values, all developments will require an authorisation issued under RSA93, prior to the start of groundwater abstraction, for the accumulation and disposal of the fluids that flow back as radioactive wastes."* In my

[9] CCoF 133: Public Health England. 2012. Review of Potential Public Health Impacts of the Exposure to chemical and radioactive pollutants as a result of shale gas extraction. PHE, London available from http://www.hpa.org.uk/Publications/Environment/PHECRCEReportSeries/PHECRCE002/.

[10] correct to 2 significant figures

view, SEPA should be asked whether it intends to grant such Authorisations and, if so, under what conditions - especially whether maxima for nuclide concentrations in outflows and annual amounts will be stipulated, and whether radon gas emissions will be included.

## E. Health Effects

25. A major question which hangs over the proposed CBM activities at Airth is - are there adverse health effects from the anticipated levels of radioactive emissions and discharges? This is a difficult question to answer because we have few general studies on health detriments from NORM discharges at oil and gas wells, and no 'hard' studies, ie no epidemiological research, certainly none on NORM discharges.

26. The one general health study which has considered radioactivity (CCoF 133) was from the Government's advisory body, Public Health England. It concerned fracking rather than CBM extraction. It concluded *"The currently available evidence indicates that the potential risks to public health from exposure to the emissions associated with shale gas extraction are low if the operations are properly run and regulated."* A problem is that SEPA has recently admitted that it is unable to fully regulate proposed CBM activities at Airth. In The Times[11] dated 15 Feb 2014, SEPA stated that it cannot guarantee it will be able to monitor potential gas leaks from Dart's proposed CBM activities. It stated "…*we are unable to state definitively at this point that we will regulate the fugitive methane emissions from the wellheads*."

27. In addition, the PHE report did not provide a completely clean bill of health re fracking. For example, it pointed (page 24) to "*a number of shale gas extraction activities that may impact surface and groundwater and hence have the potential to impact upon drinking water quality:*

- *Production and storage of fracking fluid and flowback water on site and the possibility of spills from stored ingredients or mixtures which may percolate to subsurface aquifers or may enter surface water courses.*
- *Well blow out during well completion resulting in contamination of surface waters and also possible impacts on ground water.*
- *Use of fracking fluids and possible contamination of aquifers during injection and flow back if well integrity is not maintained.*
- *Release of volatiles during fracking and the possibility of methane and other gases reaching aquifers through poor well integrity and/or through fissures in the strata.*
- *Treatment and disposal of wastewaters during transportation off-site or improper waste treatment prior to discharge, which may result in possible contamination of surface waters.*
- *Water resource and acquisition since large volumes are required for borehole drilling and hydraulic fracturing (not being considered in this evaluation)."*

It also added eight detailed recommendations as regards any future fracking activities. In sum, the PHE report certainly does not dispel concerns on possible health effects from the proposed CBM activities at Airth.

28. The health question is difficult to answer for other reasons. In particular, the long-term health effects of exposures to the low levels of radiation which are envisaged here are controversial, so that steering a 'middle' or reasonable course is fraught. Just one, albeit important, aspect shows how problematic the matter is: the Linear No Threshold (LNT) theory of radiation's effects. The theory states that radiogenic risks decline linearly all the way down to zero at zero dose without a threshold. This means there is no 'safe' level of radiation dose: all doses no matter how low will result in some health detriment, although a correspondingly low one. The world's radiation protection authorities (UNSCEAR, ICRP, WHO, PHE, IAEA etc) accept and apply this theory as much epidemiological, cell, animal and theoretical evidence points to its validity. The problem is that some non-scientist journalists and ill-informed observers refute the LNT theory.

[11] CCoF 291: Horton, J. (2014). Watchdog raises safety fears over potential leaks at methane gas plant. The Scottish Times. http://www.thetimes.co.uk/tto/news/uk/scotland/article4006665.ece

29. It is recommended that the Reporters accept the LNT theory along with the world's radiation protection authorities. This means that, even if the levels of radioactive gas emissions and radioactive water discharges at Airth were low, some level of health and environmental detriment, though low, would still be expected to occur.

30. The question remains … would this level of detriment be acceptable particularly when balanced with any economic benefits which might or might not accrue? To answer this, estimates of radiation exposures to those members of the public most likely to be affected and to the workers concerned (ie individual doses), and to the populations concerned (ie collective doses) from the envisaged emissions and discharges are often assessed. Assessments are also often made of detriments to non-human biota.

31. From its Supporting Information document (DE 60), Dart Energy has carried out some of these assessments (see pages 13-17): collective doses and occupational doses were not estimated. The remaining assessments in my view have been carried out conscientiously with one major omission – estimates of exposures from radon gases. However even if these were included, it is doubtful they would change the resulting estimated doses by a large factor. In other words, the numerical dose estimates would remain very small.

32. The difficulty is that such dose assessments are highly dependent on estimates of internal exposures via ingestion and inhalation of the radionuclides discussed above. Such dose estimates were discussed in detail in the 2004 Report of the Government's CERRIE Committee[12] on the risks of internal radionuclides. This concluded that considerable uncertainties existed with estimates of radiation doses from intakes of internal emitters. It is noted that none of the various dose estimates in the Dart Supporting Information Report contains uncertainty estimates.

33. In my opinion, the various dose estimates in pages 13-17 of Dart's Supporting Information report re health effects are surrounded by large numerical uncertainties, perhaps as much as by two to three orders of magnitude. In such circumstances, the Precautionary Principle should be applied. According to the European Commission, the Precautionary Principle is used when a process etc may have a dangerous effect as identified by scientific and objective evidence, but the risk cannot be determined with sufficient certainty.[13] In essence, this means that we should err on the side of caution, and not proceed with the process.

## F. Conclusions

34. Any decision by the Reporters on Dart Energy's application should await satisfactory outcomes on the following:

- Baseline studies to establish pre-operation levels of radon-222 and radon-220 gas emissions.
- SEPA's decision on whether to grant Authorisation(s) and, if so, under which conditions.
- [*bullet-point deleted*]

35. In essence, Dart Energy's CBM extraction proposals would result in the discharge of ~ 1.7 GBq (billion becquerels) of radioactivity in produced water each year to the river Forth and the transportation of ~ 0.2 GBq of radioactivity in sludge to licensed radioactive waste dump sites. These are relatively large amounts of radioactivity and, on balance, and in line with the Precautionary Principle, I would caution against allowing Planning Permission being granted to the CBM extraction proposals at Airth.

[12] CCoF 292: CERRIE. (2004). Report of the Committee Examining Radiation Risks of Internal Emitters Available from www.cerrie.org.

[13] CCoF 293: "The Precautionary Principle" (Europa, 2011), http://europa.eu/legislation_summaries/consumers/consumer_safety/l32042_en.htm.