HIROSAKI UNIVERSITY

Radiation Environment and Medicine 2017 Vol.6, No.2 49–54

REM
Radiat Environ Med

Special Contribution

Radiation Monitoring in Ireland – The Impact and Lessons Learned from Nuclear Accidents

Kevin Kelleher*

Office of Radiation Protection and Environmental Monitoring, Environmental Protection Agency, 3 Clonskeagh Square, Clonskeagh Road, Dublin 14, Ireland

Received 24 February 2017; revised 25 April 2017; accepted 15 May 2017

The Environmental Protection Agency (EPA) Ireland monitors both natural and man-made radioactivity in the Irish environment. This radiation monitoring programme has evolved over time as a result of legislative requirements, the inventory of anthropogenic radioactivity in the Irish environment and as a response to nuclear accidents. The three most significant nuclear accidents from an Irish perspective are the Windscale fire in October 1957, the Chernobyl accident in May 1986 and the Fukushima accident in March 2011. As a result of these accidents, the radiation monitoring capabilities and expertise in Ireland has increased and there have been significant developments in the areas of emergency preparedness and response to nuclear accidents. In order to respond effectively to nuclear accidents it is important that Ireland maintains an integrated comprehensive monitoring network, engages all relevant stakeholders, communicate effectively and to continue to develop resources taking into account the lessons learned from past accidents and international best practice.

Key words: Radiation monitoring, nuclear accidents, emergency response, Windscale, Chernobyl, Fukushima

1. Introduction

The Environmental Protection Agency (EPA), Ireland monitors the levels of radioactivity in the Irish environment. The key elements of the EPA's radioactivity monitoring programme are the assessment of:

- ambient radioactivity in air and of external gamma dose rate,
- radioactivity in foodstuffs and drinking water
- the geographical and temporal trends of artificial radioactivity in the Irish marine environment.

The radioactivity monitoring programme is conducted by the EPA in order for Ireland to fulfil a number of statutory requirements and international commitments with regards to radioactivity monitoring. Prior to the EPA assuming responsibility for radioactivity monitoring in 2014, monitoring was carried out by the Radiological Protection Institute of Ireland (RPII: 1992-2014) and its predecessor, the Nuclear Energy Board (NEB: 1973-1992).

The EPA's radioactivity monitoring programme has evolved over time as a result of new legislative requirements, the inventory of anthropogenic radioactivity in the Irish environment and as a response to nuclear accidents. In the present study, an outline of Ireland's response to three nuclear accidents is outlined along with the impact of the accidents on Ireland and the lessons learned.

*Kevin Kelleher: Radiation Monitoring, Office of Radiation Protection and Environmental Monitoring, Environmental Protection Agency, 3 Clonskeagh Square, Clonskeagh Road, Dublin 14, Ireland
E-mail: k.kelleher@epa.ie (Dr. Kevin Kelleher)

Table 1. Estimated Inventory of selected radionuclides released during the Windscale Fire

Radionuclide	Activity (PBq)	Radionuclide	Activity (PBq)
^{137}Cs	22	^{89}Sr	5.1
^{131}I	740	^{90}Sr	0.07
^{210}Po	8.8	^{129m}Te	25
^{239}Pu	0.002	^{132}Te	440
^{106}Ru	3	^{33}Xe	12,000

2. The Windscale Fire (1957)

2.1. Overview of the Accident

The "Windscale Piles" were located on the North-West coast of England (currently the Sellafield site) approximately 80km from the North-East coast of the Republic of Ireland. These Piles were nuclear reactors developed by the United Kingdom Atomic Energy Authority (UKAEA) in order to produce plutonium for use in nuclear weapons. The Piles were air cooled, graphite moderated piles each fueled by 180 tonnes of uranium metal. Pile No. 1 became operational in October 1950 and Pile No. 2 became operational in October 1951. The construction design of the two Piles was such that it made the graphite moderator in the reactors susceptible to 'Wigner Energy'. Wigner Energy is a form of potential energy in the graphite moderator caused by the displacement of carbon atoms in the lattice of the graphite as a result of neutron irradiation. When the displaced carbon atoms return to their original state there is a release of the Winger Energy in the form of heat[1)]. Thus, in order to prevent overheating of the core, controlled annealing procedures on the graphite in the cores were carried out on a regular basis.

During the ninth anneal in Pile No. 1 in October 1957 a fire broke out in the core, releasing nuclear contaminants from the core and into the environment over a period of approximately 24 hours[2)]. The details of the accident have been described in greater detail elsewhere[3)]. The estimated inventories of specific radionuclides released as a result of the accident are outlined in Table 1[4)], these releases were mainly radionuclides of the noble gases and volatile elements.

The release of radioactive material from the pile chimney was the worst accidental discharge of radionuclides in the UK and has since been classed as an "accident with wider consequences" by the International Atomic Energy Agency (IAEA), being designated as Level 5 on the International Nuclear Event Scale (INES)[5)]. However, the contamination from the accident could have been far worse with some, but not all, of the radioactive particles released from the core being blocked by filters installed on the Pile's chimney stacks at the request of Sir John Cockroft late in the construction of the stacks[6)].

2.2. Impact on Europe and Ireland

A retrospective assessment of the accident was conducted and it estimated that the dispersion of radioactivity from the Windscale Fire was predominantly to the East of the site, across the UK and further on to Western Europe[7)]. The plume from the accident extended across the whole of England and Wales and towards the east coast of Ireland. It also extended over a large area of Western Europe. During the dispersion of the plume, weather records across Europe indicated very little rainfall so wet deposition from the accident would not have been an issue. Traces of radioactivity from the accident were detected in France, Germany, the Netherlands, Belgium, Norway and Switzerland[8)].

Based on the prevailing weather conditions at the time it is highly unlikely that radioactivity from the Windscale fire could have reached Ireland before the 15th of October. At this late stage the plume would have been more diffuse and dispersed having followed a circuitous route via Southern England.

At the time of the Windscale Fire, airborne radioactivity measurements were being conducted on a routine basis by the Irish Meteorological Service in Dublin, on the east coast, and in Valentia, on the west coast of Ireland. These measurements were being conducted in order to measure airborne radioactivity levels as a result of nuclear weapons testing that commenced in the early 1950's. Total beta activity of particulate matter was measured along with radioactivity in settled dust and precipitation using Geiger counting systems calibrated using certified radioactivity standards. Data from October 1957 indicates that there was no statistically significant rise in airborne radioactivity measurements, precipitation or settled dust in Dublin or Valentia in the days following the Windscale fire. The highest measured values in the month of October 1957 were made before the fire on the 9th of October and these are thought to be as a result of fallout from nuclear weapons testing occurring at the time[9)].

Studies in the 1980's concluded that the risk of thyroid cancer from exposure to I-131 was the greatest radiological impact of the fire with health effects from the exposure of Po-210 also being of significance. These studies attributed an additional 33 fatal cancers in the UK and Western Europe to the Windscale Fire[10)]. In 1990, an additional study using updated cancer coefficients estimated that the cancer had caused approximately 100 fatal cancers and approximately 90 non-fatal cancers. The additional fatal cancers being attributed to Po-210 rather than I-131[11)]. To date, there is no convincing evidence that the Windscale Fire had a significant radiological impact on the Irish population[12)].

Table 2. Estimated Inventory of selected radionuclides released during the Chernobyl Accident

Radionuclide	Activity (PBq)	Radionuclide	Activity (PBq)
^{85}Kr	33	^{89}Sr	~115
^{133}Xe	6,500	^{90}Sr	~10
^{129m}Te	240	^{103}Ru	>168
^{132}Te	~1,150	^{106}Ru	>73
^{131}I	~1,160	^{140}Ba	240
^{133}I	910	^{95}Zr	84
^{134}Cs	~47	^{99}Mo	>72
^{137}Cs	36	^{141}Ce	84
^{136}Cs	~85	^{144}Ce	~50

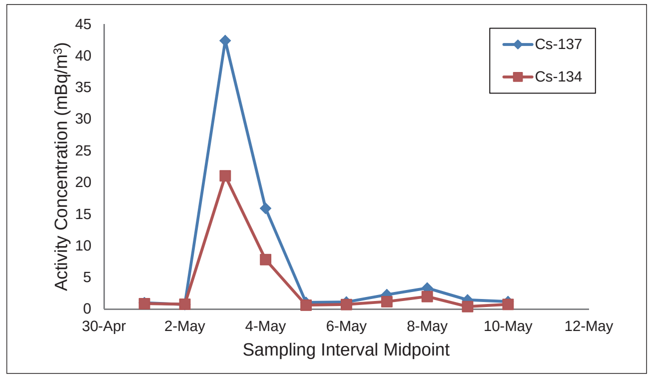

Fig. 1. Radiocesium concentrations in airborne particulates in Dublin, May 1st–10th 1986.

2.3. Lessons learned

The Windscale Fire highlighted the necessity of extensive monitoring of air, food and water in the event of a nuclear accident. In the days following the accident an extensive survey was conducted in the region surrounding the Windscale Piles that sought to determine the dose from external radiation, the dose through inhalation of radioactivity and the dose arising from ingestion of contaminated food and water[13].

During this survey I-131 was quickly identified as a radiological hazard and so health physicists derived an acceptable limit for the level of I-131 in milk to constrain thyroid doses to infants and children. This led to a restriction on the distribution of milk in areas surrounding the Windscale site and limited individual thyroid doses as well as the collective thyroid dose to the population in the local area[14].

The Windscale Fire highlighted the importance of monitoring discharges from Sellafield from an Irish perspective and led to the development of a National Radiation Monitoring Service (NMRS) in Ireland in the late 1960's[15].

3. The Chernobyl Accident (1986)

3.1. Overview of the Accident

The Chernobyl accident occurred on the 26th April 1986 during a controlled shutdown of reactor number four at the Chernobyl nuclear power plant in the Ukraine (formerly the USSR). It was caused by an experiment to test a way of cooling the core of the reactor in an emergency situation. This test led to an explosion that ruptured the reactor casing, dispersed the core and led to a graphite fire. The accident was as a result of design deficiencies, a series of human errors and the reactor being brought into an unstable condition[16]. The consequences of this accident have framed a lot of what is done in the EPA today with regards to radiation monitoring and emergency preparedness.

The accident released a mixture of radionuclides into the atmosphere over a period of ten days. An estimate of some of the radionuclides released are outlined in Table 2[17]. The Chernobyl accident was classed as level 7 on the INES scale–A major accident, in comparison to the Windscale Fire, the quantity of I-131 released was approximately 1000 times greater.

3.2. Impact on Europe and Ireland

The initial explosion released an inventory of radionuclides high into the atmosphere, and consisted of gases, aerosols and finely fragmented nuclear fuel particles. The release was of a very long duration of approximately ten days[18]. Radioactive contamination of the ground was found to some extent in nearly every country in Europe[19]. Radioactivity from the Chernobyl accident was first detected in Europe (and outside the USSR) at a nuclear power plant in Forsmark, Sweden two days after the accident on the 28th April, 1986[18] and the accident was confirmed later that day by the USSR authorities. After the initial alert by authorities in Sweden, monitoring for radioactive contamination was increased by all European countries. Radioactive contamination was first detected in Ireland on the 2nd May 1986. A significant increase in airborne radioactivity was detected on an air filter sample collected in Dublin during a 24 hour time period from 10 am on the 2nd May to the 3rd May. The following day the radioactive contamination had fallen to approximately one third of those on the previous day (Figure 1). Little, if any, contamination was detected on air filters collected after this time period and airborne activity concentrations returned to their pre-accident levels. The main radionuclides detected were I-131, Cs-137, Cs-134, Ru-103, Ru-106, Te-132/I-132 and Ba-140/La-140, with trace levels of other radionuclides detected. The rapid decrease combined with the meteorological conditions at the time indicated that contamination had been limited to the period of May 2nd to 5th 1986, with the major contamination most likely to have occurred on the 3rd

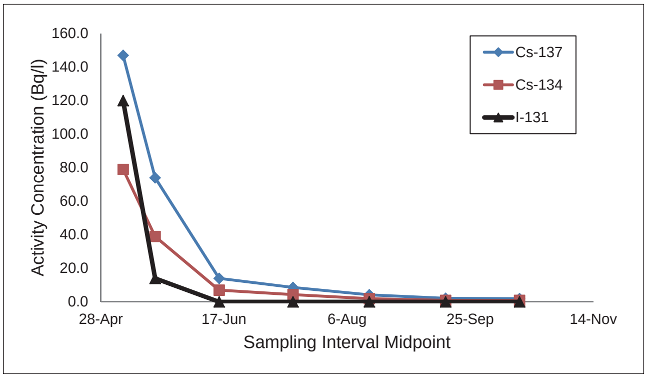

Fig. 2. Mean radioactivity concentrations in milk. May-October 1986.

May[20]. The contamination was lower than that reported for other European countries. However, the prevailing weather conditions during the passage of the plume included heavy rainfall that varied considerable at a local and regional level that led to contamination as a result of wet deposition but it varied considerably from location to location. As a result of this a major environmental monitoring programme was initiated to determine the level and distribution of the deposition, the contamination of foodstuffs and the potential radiation exposure of members of the public.

Once it became clear that the dose arising external exposure or inhalation exposure was likely to be of major significance monitoring of ingestion pathways began with the monitoring of drinking water supplies being prioritized. In general no detectable increases above background were found apart from three reservoirs were traces of contamination were found (< 5 Bq/l).

The radionuclide of most immediate importance after deposition was I-131 as it is readily concentrated in milk. The other radionuclides of importance were Cs-134 and Cs-137. Sampling and analysis of milk commenced as soon as airborne contamination was detected. Contamination in milk samples was first detected on the 4th May. From this date onwards, sampling was conducted over a network of sampling locations around the country. The results of measurements can be seen in Figure 2.

Other foodstuffs that were monitored included vegetables, dairy products, beef and lamb. In addition, foodstuffs imported were extensively tested, these are outlined in greater detail elsewhere[20].

The estimates of the radiological impact on the Irish public, based on measurements made during the first six months after the accident indicated that the effective doses to members of the Irish public in the year following the accident were:

- 99 µSv for adults
- 105 µSv for ten year old children and
- 158 µSv for one year old children

Estimates, based on risk factors produced by UNSCEAR, have indicated that these dose rates could possibly give rise to an additional 5–25 additional fatal cancers in the Irish population in the 70 years following the accident[20].

3.3. Lessons learned

The most important lesson learned from the Chernobyl accident was the need for a comprehensive environmental monitoring network with clearly defined objectives that is capable of responding to elevated levels of radioactive contamination. The Chernobyl accident also demonstrated the need to provide extensive monitoring in support of the Irish agricultural industry. These issues were addressed by the European Commission through the development of new legislation that required Member States to develop radioactivity monitoring programmes[21] and early warning systems and to allow the rapid exchange of radiation monitoring data in the event of a nuclear emergency[22, 23]. The accident also led to the development of internationally recognized criteria for the protection of the public in the event of a nuclear accident[24]. As a result of the accident, the Irish government developed their own National Emergency Plan for Nuclear Accidents (NEPNA)[25].

4. The Fukushima Accident (2011)

4.1. Overview of the Accident

The Great East Japan Earthquake and associated tsunamis on 11 March 2011 resulted in the complete loss of power and reactor cooling to the Fukushima Dai-ichi Nuclear Power Plant (FD-NPP). This resulted in the development of severe accident conditions at FD-NPP and, subsequently, large releases of radioactivity into the environment. The full sequence of events that followed the earthquake and tsunami is described in greater detail elsewhere[26]. The accident released radioactivity into the atmosphere and into the marine environment as a result of venting operations and hydrogen explosions with the majority of the releases to the atmosphere occurring during the period 12 to 22 March, with a maximum release phase from 14 to 17 March. The radioactivity released was dominated by volatile fission products including isotopes of the noble gases xenon and krypton; iodine; caesium; and tellurium. Like Chernobyl, this accident was classed as level 7 on the INES scale – a major accident.

4.2. Impact on Europe and Ireland

Following the first reports of atmospheric releases from FD-NPP radioactivity in air monitoring activity across the northern hemisphere was increased. The first European detection was between the 19th and 20th March in Iceland, where radioactivity from FD-NPP was detected by a

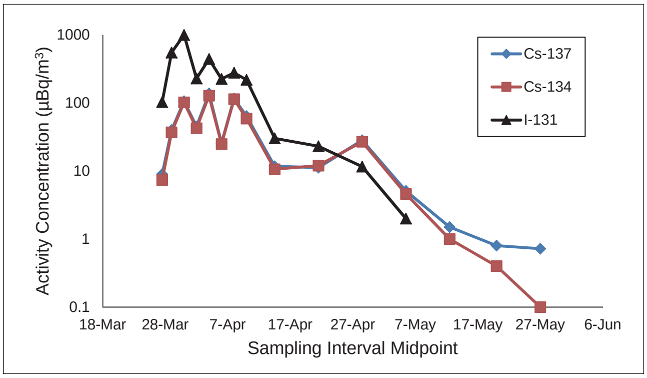

Fig. 3. Radioactivity in Airborne Particulates (High Volume), Belfield, Dublin (Mar–May 2011).

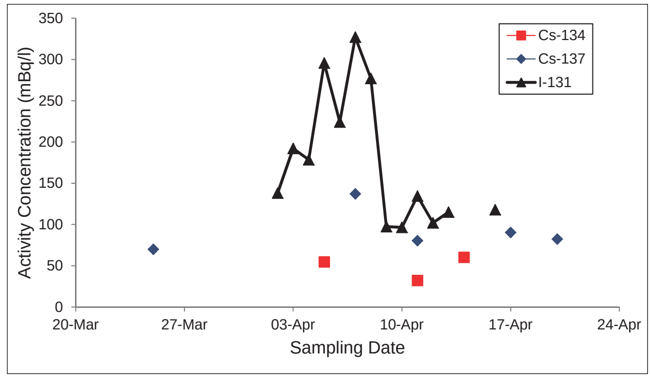

Fig. 4. Radioactivity in Airborne Particulates (High Volume), Belfield, Dublin (Mar–May 2011).

Comprehensive Test Ban Treaty Organisation (CTBTO) monitoring station. By the 24th March radioactivity from FD-NPP was detected in most of the other European countries[27]. Due to the transit time of the radioactivity and the significant dilution of the plume as it crossed the Northern Hemisphere the radioactivity concentrations detected were extremely small and not of concern from a public health point of view.

On March 22nd 2011 the RPII made the decision to increase the frequency of sampling and analysis of air, rainwater and milk in Ireland in anticipation of the arrival of the radioactive plume. Sampling frequencies were increased to daily or every two days for airborne particulates. Raw milk samples were collected from a large dairy facility in Kilkenny, located in the south-east of Ireland on a daily basis. Trace amounts of radioactive isotopes consistent with the Fukushima accident were detected in Ireland from the 24th March to late May 2011. The Cs-137, Cs-134 and I-131 results from the High Volume sampler, capable of sampling up to 2500 m^3/h of air, can be seen in Figure 3. Other radionuclides detected included Cs-136 and Te-132/I-132, which were consistent with atmospheric discharges from FD-NPP. The activities detected were at levels so low as to be of no radiological significance to Ireland and no protective measures were required and the levels detected were consistent with those found elsewhere in Europe.

The milk samples collected were also analysed for the gamma emitting radionuclides Cs-134, Cs-137 and I-131. The results of the milk monitoring can be seen in Figure 4.

The highest measured activity concentration of this radionuclide was 327 ± 36 mBq/l on 7th April 2011. Cs-134 and Cs-137 were measured at just barely detectable amounts in some of the daily milk samples analysed.

4.3. Lessons learned

The accident proved a good test of Ireland's capacity to respond effectively to a nuclear emergency. As a result of lessons learned from the Chernobyl accident and subsequent legislation arising from the accident in 1986 the EPA now has a comprehensive monitoring network capable of measuring even trace levels of radioactivity and has also demonstrated the effectiveness of atmospheric dispersion modelling as part of its technical assessment capability.

However, for a nuclear accident closer to Ireland, a much larger monitoring response would almost certainly be required.

The Fukushima accident also highlighted the RPII's reliance on all of the stakeholders involved in Ireland's NEPNA, particularly those involved in the collection and delivery of samples to the monitoring laboratory and the provision of up to date meteorological data as events unfolded.

Collaboration with international bodies such as the IAEA, European Commission and other national organization's conducting radioactivity measurements was also important.

5. Conclusion

The EPA continues to monitor the levels of ambient radioactivity in the Irish environment to assess the geographical and temporal trends of both natural and man-made radioactivity and maintains the equipment and personnel to ensure it can effectively respond to a nuclear accident in the future. The radiation monitoring capabilities in Ireland have evolved in response to nuclear weapons testing, the development of nuclear power plants / nuclear reprocessing facilities, the dumping of nuclear waste and as a result of nuclear accidents in Europe and around the world.

In order to ensure we continue to respond effectively to nuclear accidents and incidents into the future there is a need to:

- Maintain and continue to develop a comprehensive monitoring programme.

- Engage all relevant stakeholders, both nationally and internationally so that all appropriate resources are available to us.
- Communicate to members of the public as situations evolve during nuclear accidents
- Continue to develop resources in light of recent events and international best practice.

Conflict of Interest Disclosure

The author reports no conflicts of interest.

References

1. Guppy R, Wisbey S, McCarthy J. Technical Assessment of the Significance of Wigner Energy for Disposal of Graphite Wastes from the Windscale Piles. Technical Committee Meeting on Nuclear Graphite Waste Management. Manchester (United Kingdom): 18–20 Oct 1999, 2001.
2. Command 302. "The Accident at Windscale No. 1 pile on 10 October 1957," HMSO, London: 1958.
3. Arnold L. Windscle 1957. Anatomy of a Nuclear Accident, 2nd Edition. Basingstoke: Macmillan; 1995.
4. Mitchell PI. Radionuclide Dispersal Pathways: Some General Considerations and Examples, in Actinides and the Environment. Dordrecht/Boston/London: Kluwer Academic Publishers; 1998, p. 319–66.
5. Webb G, Anderson R, Nelson N. Classification of Events with an off-site radiological impact at the Sellafield site between 1950 and 2000 using the International Nuclear Event Scale. J Radiol Prot. 2006;26(1):33–49.
6. Mahaffey J. Atomic Awakening: A new look at the history and future of nuclear power. New York: Pegasus; 2010.
7. Johnson C, Kitchen K, Nelson N. A study of he movement of radioactive material released during the Windscale fire in October 1957 using ERA40 data. Atmos Environ. 2007;41(18):3921–37.
8. Stewart N, Crooks R, Fisher E. Measurements of the radioactivity of the cloud from the accident at Windscale: data submitted to the I.G.Y. report AERE-M857, UK Atomic Energy Authority, Harwell; 1961.
9. Irish Meteorological Service, Measurements of radioactivity of precipitation, settled dust and airborne particles in Ireland in 1957, Department of Transport, Dublin: 1958.
10. Crick M, Linsley G. An assessment of the radiological impact of the Windscale reactor fire, October 1957. Int J Radiat Biol. 1984; 46(5):479–506.
11. Clarke R. The 1957 Windscale accident revisited, in The Medical Basis for Radiation Accident Preparedness. New York: Elsevier; 1990, p. 281–9.
12. Gallagher D, McGee E, Mitchell PI, Alfimov V, Aldahan A, Possnert G. Retrospective Search for Evidence of the 1957 Windscale Fire in NE Ireland Using ^{129}I and Other Long-Lived Nuclides. Environ Sci Technol. 2005;39(9):2927–35.
13. Dunster HJ, Howells H, Templeton W. District Surveys follwing the Windscale incident, October 1957. Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy (Geneva, 1 September - 13 September 1958), vol. 18: Waste Treatment and Environmental Aspects of Atomic Energy, p. 296–308, 1958.
14. Editorial. The Windscale reactor accident - 50 years on. J Radiol Prot. 2007;27(3):211–5.
15. Powell M, Cross F, Egan E, McCarthy M, O'Connor J, O'Sullivan D. The national radiation monitoring service. Ir J Med Sci. 1970; 3(2):85–101.
16. INSAG. INSAG-7 The Chernobyl Accident: Updating of INSAG-1, A report by the International Nuclear Safety Advisory Group, IAEA, Vienna, 1992.
17. UNSCEAR. Report to the General Assembly with Scientific Annexes Volume II Annex D, United Nations, New York: 2011.
18. NEA. Chernobyl: Assessment of Radiological and Health Impacts 2002 Update of Chenrobyl: Ten Years on, Paris: Nuclear Energy Agency; 2002.
19. DeCort M, Dubois G, Fridmann S, Germenchuk M, Izrael Y, Janssens A, Jones A, Kelly G, Kvasnikova E, Matveenko I, Nazarov I, Pokumeiko Y, Sital V, Stukin E, Tabachny LY, Tsaturov Y, Avdyushin S. Atlas of Caesium deposition on Europe after the Chernobyl accident. Luxembourg: European Commission; 1998.
20. NEB. Chernobyl - its effects on Ireland. Dublin: Nuclear Energy Board; 1987.
21. EC. Council Directive 2000/473/EURATOM of 8 June 2000 on the application of Article 36 of the Euratom Treaty concerning the monitoring of radioactivity levels in the environment for the purpose of assessing exposure of the population as a whole, Brussels: Official Journal of the European Communites; 2000.
22. EC. 87/600/Euratom: Council Decision of 14 december 1987 on Community arrangements for the early exhange of information in the event of a radiological emergency, Brussels: Official Journal of the European Communities; 1987.
23. EC. Agreement between the European Atomic Energy Community (Euratom) and non-member States of the European Union on the participation of the latter in the Community arrangements for the early exchange of information in the event of radiological emergency, Brussels: Official Journal of the European Union; 2003.
24. EC. Council Regulation (EEC) No 737/90 of 22 March 1990 on the conditions governing imports of agricultural products originating in third countries following the accident at the Chernobyl nuclear power-station, Brussels: Official Journal of the European Union; 1990.
25. Department of Housing, Planning Community and Local Government, "National Emergency Plan for Nuclear Accidents," [Online]. Available from: http://www.housing.gov.ie/environment/environmental-radiation/national-emergency-plan-nuclear-accidents/national-emergency. [cited 23 February 2017].
26. The Fukushima Daiichi accident–Technical Volume I. The description and context of the accident. Vienna: IAEA; 2015.
27. Masson O, et al. Tracking of Airborne Radionuclides from the Damaged Fukushima Dai-Ichi Nuclear Reactors by European Networks. Environ Sci Technol. 2011;45:7670–77.