NUCLEAR MONITOR

A PUBLICATION OF WORLD INFORMATION SERVICE ON ENERGY (WISE)
AND THE NUCLEAR INFORMATION & RESOURCE SERVICE (NIRS)

wise
World Information Service on Energy
founded in 1978

NUCLEAR INFORMATION
& RESOURCE SERVICE
www.nirs.org

FEBRUARY 7, 2013 | No. 756

Late Lessons from Chernobyl, Early Warnings from Fukushima

Dr. Paul Dorfman

Adapted from: Paul Dorfman, Aleksandra Fucic, Stephen Thomas (2013): 'Late Lessons from Chernobyl, Early Warnings from Fukushima', In: 'Late Lessons from Early Warnings': Part C - Emerging Issues Section, European Environment Agency, Copenhagen.

At present, nuclear energy is used in 30 countries and Taiwan, producing roughly 13 % of the world's commercial electricity, and currently 14 countries and Taiwan are in the process of planning the building of new nuclear capacity. There are 435 nuclear power reactors in operation around the world - at the peak of nuclear generation in 2002 there were 444 - of which 189 are in pan-Europe and the Russian Federation, comprising about one third of the world's 146 civil reactors, with France alone generating close to half of the EU's nuclear production from 58 plants (Schnieder et al, 2011; European Nuclear Society, 2012).

With mounting public concern and policy recognition over the speed and pace of low carbon energy transition needed to mitigate climate change, nuclear power has been reframed as a response to the threat of global warming (IAEA, 2000; EDF, 2012; NIA, 2012; WNA, 2012). However, at the heart of the question of nuclear power are differing views on how to apply foresight, precaution and responsibility in the context of the possibility of accidents.

Aspects of Low Level Radiation Epidemiology

There are significant uncertainties associated with the choice of differing models used to interpolate radiation risk between populations with different background disease rates; for the projection of risk over time; for the extrapolation of risks following primarily a single external high dose and a high dose-rate in contrast to cumulative low dose and low dose-rate exposures (ARCH, 2010). Despite this, the analysis of incidence and distribution of disease (epidemiology) remains fundamental to radiation-risk determination and standard setting. Epidemiological investigations ranging from the Japanese atomic bomb life span survivor studies to more numerically and temporally limited studies have provided a weight of evidence about the effects of ionizing radiation on humans. Whilst a range of studies suggests no causal or associative link between routine discharges from operating nuclear plants (Jablon et al, 1991; Yoshimoto et al, 2004; Evrard et al, 2006; COMARE, 2011), this important debate is ongoing.

One of the most significant data sets in this debate comprises a national case-control study, funded and published by the Federal Office for Radiation Protection on behalf of the German Federal Ministry for the Environment and conducted by the German Childhood Cancer Registry on childhood cancer near nuclear instal-

MONITORED THIS ISSUE:

lations. This study investigated childhood leukaemia and cancer incidence near nuclear plants from 1980 to 2003, providing evidence of a significant increase in childhood leukaemia and cancer risk near to nuclear plants in Germany (Kaatsch et al, 2007; Kaatsch et al, 2008a; Kaatsch et al, 2008b; Spix et al, 2008). The German Federal Office for Radiation Protection formally confirmed these findings, stating that *“in the vicinity of nuclear power plants, an increased risk of 60 % was observed for all types of childhood cancer, and for childhood leukaemia the risk doubled equaling a risk increase of approximately 100 %”* (BfS, 2008). In response, the UK scientific advisory body Committee on Medical Aspects of Radiation in the Environment (COMARE) 14th Report (2011) critiqued the German study, and discounted the findings, noting that COMARE’s primary analysis of the latest British data had revealed no significant evidence of an association between risk of childhood leukaemia and living in proximity to a UK nuclear facility (COMARE, 2011). The Committee also pointed to the role of unidentified viral infections rather than radiation exposure in the aetiology of childhood leukaemia near nuclear power plant (Kinlen, 2011).

Subsequently, in early 2012, a further nation-wide case-controlled investigation by Institut Nationale de la Santé et de la Recherche Medicale (INSERM) on behalf of France's nuclear safety research body, Institut de Radioprotection et de Sûreté Nucléaire (IRSN), demonstrated a statistically significant doubling of the incidence of leukaemia near to nuclear plants in France between 2002 and 2007 (Sermage-Faure et al, 2012). However, neither a causal link nor an association between gaseous discharges and ill health were established.

Aspects of Low Level Radiation Biology

The theoretical underpinning of the biological effects of ionizing radiation is based on sophisticated variants of target theory, such as track structure theory. Target theory stipulates that the biological targets damaged in the cell are relevant to the endpoint: for example, damage to a tumour suppressor gene might lead to cancer. Target theory holds for single locus hereditary disease but there were problems in applying it to somatic cell endpoints such as cancer. However, in 1992 evidence inconsistent with target theory emerged in the form of two effects, genomic instability (Khadim et al, 1992) and the bystander effect (Nagasawa and Little, 1992). Such effects are collectively known as non-targeted effects because the target is large enough to encompass the whole nucleus of the cell, and radiation does not directly affect the damaged cell. Genomic instability is characterised by the acquisition, de novo, of various kinds of damage, mostly to DNA, up to several cell generations after the exposure. Damage associated with genomic instability may not be directly caused by the radiation but is a secondary response of the cell to radiation insult. The bystander effect occurs in cells that experienced no radiation events, but are neighbours of cells that have.

These phenomena pose a set of significant research questions for the understanding of the underlying mechanisms involved, and could imply the need for a re-appraisal of the target theory approach, and the emergence of a new theoretical framework for the biological bases of the effects of radiation. Perhaps the most worrying aspect from the public health perspective is the potential for trans-generationally inherited genomic instability. A number of mechanistic hypotheses have been proposed to explain genomic instability (ARCH, 2011), and Baverstock and Karotki (2011) have suggested a further explanatory conceptual framework.

Whilst two European Commission FP6 projects, RISC-RAD (http://riscrad.org/) and NOTE (http://www.note-ip.org), specifically directed at obtaining a better understanding of genomic instability, have reported – so far no replacement for the underpinning framework based on target theory has emerged. This may be because, as usual with radiation biology, the picture is complex, especially in distinguishing between the interpretation of results from in vitro and in vivo studies. Yet more recent work indicates that additional mechanisms may also be important for the understanding of the impact of genomic instability and bystander effects on radiation protection regulation: Mukherjee et al (2012) suggest that radiation-induced chromosomal instability may also result from inflammatory processes having the potential to contribute secondary damage expressed as non-targeted and delayed radiation effects. And Lorimore et al (2011) conclude that complex multi-cellular interactions resulting from bystander effects may influence carcinogenic susceptibility, with inflammatory processes responsible for mediating and sustaining the durable effects of ionizing radiation. Given that the genotype of each individual is a key determinant of carcogenic susceptibility, then genotype-directed tissue responses may be important determinants of understanding the specific consequence of radiation exposure in different individuals (ibid). One potentially significant implication of these finding is that differing people may have differing responses and susceptibilities to radiation insult.

Chernobyl

On the 26th April 1986 an explosion at the Chernobyl Nuclear Power Plant No. 4 in Northern Ukraine resulted in widespread cross-boundary atmospheric pollution by fission-product radioisotopes. Following what is understood to have been a misconceived reactor experiment, a positive void coefficient caused reactivity excursion, resulting in a steam explosion that destroyed the plant. Over the six days of open containment 30-60 % of the Chernobyl reactor core’s fission products were released to the atmosphere, 6.7 tonnes of material from the core. This material was projected high into the atmosphere, spreading radioactive isotopes over more than 200,000 square kilometers (km2) of Europe (UNDP, 2002). In response, the authorities evacuated and subsequently relocated around 115 000 people from areas surrounding the reactor; after 1986, a further 220 000 people from Belarus, the Russian Federation and Ukraine were re-settled (UNSCEAR, 2008).

Each day some 3 500 workers enter the 30 kilometre exclusion zone, established by the Ukraine, to monitor, clean and guard the site, where remediation work is likely to continue until 2065 - although less than half the resources needed to fund the remediation have been raised, and the completion date has slipped by a decade. The work includes managing the long-term storage of waste from Reactor 4, and more than 20 000 spent fuel canisters from the site's other reactors. Significant quantities of radioactive waste continue to be generated - partly due to ongoing flooding in some areas of the waste-storage buildings and Reactor 4's turbine hall, forcing the pumped discharge and on-site storage of around 300 000 litres of radioactively contaminated water per month (Peplow, 2011).

Post-Chernobyl Meta-analyses

Whilst it is outside the remit of this discussion to rehearse in detail the very broad literature on radiation risk epidemiology, it is sufficient to note that the precise estimation of acute and long-term health effects as a result of the Chernobyl accident remains problematic and subject to ongoing critique. This is because epidemiological evidence on health impacts is contradictory and conflicting. The link between radiation and the aetiology of cancer and leukaemia is well established – but the debate continues about the risks of those diseases, in particular childhood cancer and leukaemia, from Chernobyl releases and in the vicinity of other operational nuclear installations elsewhere

It is therefore unsurprising to see significant differences in the understanding and interpretation of Chernobyl health effects. The problem may be exacerbated by the nature of previous studies, which have been described as forming a patchwork rather than a comprehensive, structured attempt to delineate the overall health consequences of the accident (ARCH, 2010). Nevertheless, despite differences in the types of exposure, doses, dose rates and applied methodologies, data on the health consequences of the Chernobyl accident add to knowledge collected from atomic bomb victims and from populations over-exposed during nuclear accidents and nuclear weapons testing. Integration of the available data on related health risks gives added value in preparing radiation protection protocols and in the management of subsequent nuclear accidents, such as Fukushima.

Focusing only on Belarus, Ukraine and the Russian Federation, and no other exposed countries and populations, the International Atomic Energy Authority (IAEA) convened the Chernobyl Forum (2005) that predicted a potential total mortality of about 4 000. Discounting the significantly raised childhood thyroid cancer incidence[1] , the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2008) found no evidence of increases in overall cancer incidence or mortality rates or in rates of non-malignant disorders that could be related to radiation exposure. Both of these estimates were subject to critical analysis by Yablokov et al (2006), who suggested a higher death toll as a consequence of the Chernobyl fall-out. Based on Belarus' national cancer statistics, the study predicted approximately 270 000 cancer incidences - of which 93 000 would prove fatal. A follow-up meta-analysis, which included Belarus, Russia and Ukraine, suggested further increased predicted premature deaths as a result of the radioactivity released (Yablokov et al, 2007).

It is worth noting that UNSCEAR (2011) decided not to use models to project absolute numbers of effects in populations exposed to low radiation doses from the Chernobyl accident, because of unacceptable uncertainties in the predictions. Given that UNSCEAR (1993) and IAEA (1996) estimate a total world-wide collective dose of 600 000 person-Sieverts over 50 years from Chernobyl fallout, and the standard risk estimate from the International Commission on Radiological Protection (ICRP, 2005) is 0.057 fatal cancers per Sievert, this suggests an estimate of about 34,000 fatal cancers over that time period (Ramana, 2009). Given the widely accepted linear no-threshold radiation risk model may overstate or understate risks by a factor of two (BIER VII, 2006) - then estimates for post-Chernobyl cancer mortality extrapolation may range from 17,000 to 68,000 over 50 years.

These differences in meta-analysis estimates also obtain around post-Chernobyl leukemia aetiology: Whilst UNSCEAR (2008) suggests that the incidence of leukaemia in the general population, one of the main concerns owing to the shorter time expected between exposure and occurrence compared with solid cancers, does not appear to be elevated, the UK government scientific advisory Committee Examining Radiation Risks of Internal Emitters (CERRIE, 2004) concluded that, in the judgment of a large majority of committee members, it is likely that radioactive fallout from the Chernobyl accident resulted in an increased risk of infant leukaemia in the exposed populations.

In addition, there were immediate deaths of emergency workers and firefighters resulting from acute radiation exposure. Treatment of these people also placed hospital staff and funeral workers at risk of radiation over-exposure.

---

[1] In Belarus, the Russian Federation and Ukraine nearly 5 000 cases of thyroid cancer have now been diagnosed to date among children who were aged up to 18 years at the time of the accident (WHO, 2006).

Acute Medical Care of Chernobyl Radiation Casualties.

"By May 5, 10 days after the accident, 172 individuals, 47 of them fire fighters, had been admitted Hospital #6 with the most severe form of radiation sickness. All had visible burns, were in severe pain and had little chance of survival. It should be remembered that all medical staff entering the rooms of irradiated patients were also exposed to intensive radiation from victims whom they were supposed to treat. We should express deep gratitude to all personnel, from the reception area, sterile rooms, specialized offices and laboratorie, to dosimeter controllers for their tireless service and sacrifice. As experienced radio-biologists, we understood that some of our patients would not survive – they had received radiation doses of more than 1 000 rad, which resulted in large and deep radiation burns and the penetration of their bodies by significant amounts of radioactive material. Therefore, we planned for their funerals, including the selection of appropriate location(s) and estimates of the necessary depth of tombs to avoid increases in the radiation level above the tomb. We needed to equip vehicles that would transport the dead bodies with strong protection layers quickly so as not to harm the drivers and to avoid radiation pollution between the hospital and the cemetery" (Grigoriev, 2012).

Despite these challenging circumstances it is important to note that, thanks to round-the-clock care over many months by a dedicated team of doctors, and through a wide range of holistic treatments, the lives of many patients with acute radiation sickness were saved (Grigoriev, pers com, 2012)

Fukushima Dai-ichi

On 11 March 2011, the Japanese Great Easter Earthquake, involving 5 to 10 metres of slip motion on fault zones more than 100 kilometers in length along the Japanese Trench Subduction Zone, struck the east coast of Japan triggering the shut down of 10 operating nuclear power plants. At the time of the earthquake, Fukushima Dai-ichi units 1, 2, and 3 were operating at full power (Marshall and Reardon, 2011). The plants, designed to withstand a maximum 8.2 earthquake on the logarithmic Richter scale, received a seismic shock 9-15 times higher than the design limit (Park, 2011). At the time of the accident, the radiological inventory at risk within the 6 reactor cores comprised 487 tonnes of uranium, of which 95 tonnes include 6 % plutonium from the Mox assemblies[2] . There were a further 1 838 tonnes of stored spent fuel on the site, including 1 097 tonnes in the central pool store (Large, 2011a).

At the Fukushima Dai-ichi No.1 plant, site emergency diesel generators provided on-site power to the reactor cooling pumps and other essential services of the three operating nuclear plants, as well as cooling for the six-reactor unit spent fuel ponds, and also for the central spent fuel store (Brumfiel and Cyranoski, 2011a). On-site power supplies continued in operation for just over one hour until the entire site was swamped by a 15 metre tsunami with the total wave height amplified by the backwash as the tsunami wave was contained and reflected by the heavily terraced western section of the site. This part of the site contained four reactors, three of which had been fully operational at the time of the earthquake, resulting in the failure in two or three of the nuclear power plants robust sealed containment structures as water poured into the plants (Large, 2011b)[3]

Japanese Earthquakes and Tsunamis

Minoura et al (2001) conclude that traces of large-scale invasion tsunami recorded in the coastal sequences of the Sendai plain show an approximate 1 000-year re-occurrence interval, noting that more than 1 100 years have passed since the historic Jgan tsunami and, given the reoccurrence interval, the possibility of a large tsunami striking the Sendai plain was high. Their findings indicated that a tsunami similar to Jgan would inundate the present coastal plain for about 2.5 to 3 km inland. More recently, post-Fukushima, the University of Tokyo's Earthquake Research Institute concluded that risk of a large-scale earthquake in the region has risen considerably since the Great East Japan Earthquake of 2011. This implies that, since neither practical nor theoretical models can properly determine the dynamics of imminent large earthquakes, much greater emphasis may need to be placed on natural hazards for nuclear risk assessment (Park, 2011).

The collapse of the Japanese electricity distribution grid resulted in the shut-down of individual nuclear power plant's electricity systems, resulting in loss of essential reactor fuel cooling and crucial instrumentation and control systems. This loss of offsite power and onsite AC power combined with the rapid discharge of DC batteries led to a complete station blackout which disabled the emergency core cooling systems which, in turn, disabled the monitoring of critical parameters such as reactor water levels and open critical safety valves, cascading to significant fuel and containment overheating and damage (Buongiorno, 2011). As Tokyo Electric Power Company (TEPCO) was unable to restore either on or off-site power; the entire Fukushima Dai-ichi nuclear complex went into, and remained, in station blackout.

---

[2] Mox (mixed oxide) is a form of nuclear fuel designed for use in breeder reactors, consisting of a blend of uranium and plutonium oxides.

[3] According to the Japanese Commission tasked with reviewing the disaster, the tsunami that struck the plant was twice as high as the highest wave predicted by previous risk assessments, and the assumption made by Tokyo Electric Power Company (TEPCO) that the plant's cooling system would continue to function after the tsunami struck worsened the disaster (The Investigation Committee, 2011).

The blackout meant that no safety systems remained intact, just passive design features and defense in depth layers – representing a beyond design base accident. In Unit 1, steam was bubbled through the suppression pools, further increasing water temperature, and water leaving the core was not replaced. As the water dropped below the top of the fuel, the temperature in the fuel and cladding began to rise rapidly, causing fuel degradation. The zirconium in the cladding oxidized, releasing hydrogen into the containment dry-well, and after a short time,

pressure levels in the containment were at or above the design pressure, raising risk of containment rupture. In response, operators manually opened valves to release steam from containment into the reactor building, and the vented steam containing hydrogen violently and exothermally ignited, destroying the reactor building, allowing gaseous fission products to escape, and exposing elements of the spent fuel to open containment.

Units 3 and 4 soon experienced similar beyond design-based cascading conditions. At this point, elevated radiation levels of several fission products including Cs-137 and 1-131 were detected at the reactor buildings, and the plant boundary; providing the first indication that some fuel in the reactor had already melted (Butler, 2011). The presence of hydrogen and these volatile fission products in the released steam suggested that the temperature had severely damaged the fuel cladding inside the reactor pressure vessel (Bonin and Slugen, 2011).

Backup generators and batteries arrived some hours later, restoring partial power to plant, but these were insufficient to power any of the cooling pumps; instead smaller ad-hoc fire pumps were used to pump boranated seawater into the reactor core and containment.

Within a few hours the reactor cores of the three operating units were subject to varying degrees of meltdown. The molten fuel had slumped to the bottom of the reactor pressure vessels, the reactor pressure vessels themselves had failed and, in various degrees, the primary containment of the pressure suppression system had failed. What remained of the reactor instrumentation clearly indicated an ongoing and deteriorating situation – with thermal activity within the reactor buildings resulting in sharp perturbations in containment pressure and radiation levels, particularly within what remained of the primary containment. Doubts about the effectiveness of water injection, and increasing concerns about the volumes of highly contaminated water have been linked to TEPCO's necessary emergency seawater cooling strategy, which also involved unconventional cooling efforts with helicopter and water cannons over the period of a week.

Fukushima Dai-ichi Radiation Releases: Cross Boundary Pollution

The multiple meltdown of reactors at the Fukushima Daiichi nuclear plant released more radiation than any accident since Chernobyl. Japanese regulatory officials initially assessed the accident as Level 4 on the International Nuclear Event Scale (INES), with the risk level successively rising to 5 and eventually to the maximum of 7 – a rating equal to the Chernobyl disaster. Of primary concern were fission products, readily absorbed by the human body, and the actinides, which act as heavy metal poisons. Caesium 137 (Cs-137) represents the most significant long-term hazard since it is readily taken up in human metabolic, environmental, and agricultural systems.

Early measurements reported from the United States, more than 7 000 km from Fukushima, confirmed maximum concentrations of radioxenon (Xe-133) in excess of 40 becquerel per cubic metre (Bq/m3) – more than 40 000 in excess of normal expected average concentration (Bowyer et al, 2011). High activity concentrations of several man-made radionuclides (I-131, I-132, Te-132, Cs-134 and Cs-137) were detected along the Iberian Peninsula from 28 March to 7 April 2011, deduced through back-trajectories analysis, and verified by activity concentrations (Lozano et al, 2011). Other elevated levels were recorded in air sampling, rainfall and sheep's milk at Thessaloniki, Greece (Manolopoulou et al, 2011). In April and May 2011, fallout radionuclides (Cs-134, Cs-137, I-131) were detected in environmental samples in Krasnoyarsk, Russian central Asia. Similar maximum levels of I-131 and Cs-137/Cs-134 and I-131/Cs-137 ratios in water samples collected in Russia and Greece suggested the high-velocity global movement of radioactive contamination from the Fukushima nuclear accident (Bolsunovsky and Dementyev, 2011); as did results from the Russian rapid response Typhoon monitoring system

Typhoon Monitoring System

For hazardous facilities located close to larger cities, early stage accident detection, monitoring and warning systems are critical – as they allow for better impact prediction and mitigation of human and environmental consequences. During the Fukushima accident, Typhoon, the early monitoring network associated with the Russian Early Warning and Emergency Response System (REWERS), carried out operational analysis and forecasting for this large-scale radioactive emergency. The monitoring was achieved through a network of observational stations, with radiometric laboratories providing the measurement data for environmental samples. The first Fukushima air mass transfer dispersion calculations made by Typhoon's experts were carried out on the evening of 11 March and on 12 March – the radiation monitoring network of Roshydromet in the Russian far east was set to rapid measurement mode to obtain radionuclide dose rate measurements every hour. Throughout the accident period at Fukushima, Typhoon co-operated with the IAEA and the World Meteorological Institute in performing calculations and assessments of trans-boundary emissions (Shershakov, 2011).

Post-Fukushima Dai-ichi Radiation Releases: Japan

The very high population density near the damaged reactors and spent fuel dispersions implies increased risk for local communities. The regulators conducted an initial evacuation of 100 000 people from around Fukushima, and after some hesitation, Japan's Nuclear Safety Commission established a new 20 km evacuation zone, with a further 90 000 people evacuated. Because damaged plant monitoring proved unreliable – on at least four occasions TEPCO retracted findings on the amount and composition of radionuclides in areas in and around the plant, or on reactor parameters – it has been suggested that more complete analyses of reactor-event scenarios and release fractions can be derived from outside Japan (Nature, 2011a).

The radiation releases dispersed according to the wind direction and weight of the particles. The radionuclides of interest were I-131, primarily linked to thyroid cancer; Cs-134 and Cs-137, primarily linked to bladder and liver cancer; and strontium, primarily linked to bone disorder and leukaemia. Significantly, there is confirmed isotopic evidence for the release of plutonium into the atmosphere and deposition on the ground in northwest and south of the Fukushima nuclear site (Zheng, 2012).

In September 2011, Japan's Nuclear and Industrial Safety Agency (NISA) estimated that the Fukushima Daiichi plant had released 15 000 terabecquerels Cs-137 to air. Other estimates vary. However, it may well be too early to accurately estimate or determine the scale of the damage and radiological releases (Cyranoski and Brumfiel, 2011). A meta-analysis comprising radionuclide measurement data and atmospheric dispersion modeling (Stohl et al, 2011), reported in Nature (Brumfiel, 2011), suggested that the disaster at Fukushima Daiichi may have released far more radiation than Japanese regulatory estimates; concluding that the emissions started earlier, lasted longer, and were therefore higher than earlier official estimates assume. The study noted that:

"While at first sight it seemed fortunate that westerly winds prevailed most of the time during the accident, a different picture emerges from our detailed analysis. Exactly during and following the period of the strongest Cs-137 emissions on 14 and 15 March as well as after another period with strong emissions on 19 March, the radioactive plume was advected over Eastern Honshu Island, where precipitation deposited a large fraction of Cs-137 on land surfaces. The plume was also dispersed quickly over the entire Northern Hemisphere, first reaching North America on 15 March and Europe on 22 March. In general, simulated and observed concentrations of Xe-133 and Cs-137 both at Japanese as well as at remote sites were in good quantitative agreement with each other. Altogether, we estimate that 6.4 TBq of Cs-137, or 19 % of the total fallout until 20 April, were deposited over Japanese land areas, while most of the rest fell over the North Pacific Ocean. Only 0.7 TBq, or 2 % of the total fallout were deposited on land areas other than Japan." (Stohl et al, 2011, p. 28322).

In other words, Fukushima releases may have contained an estimated 3.5 × 1 016 Bq Cs-137 – roughly twice the official government figure, with almost one fifth falling on the Japanese mainland. This means that the Fukushima release can be estimated to equal to 40 % of the Cs-137 release from Chernobyl.

By November 2011, the air radiation level in Ibaraki Prefecture was about 0.14 microsievert per hour, equivalent to an annual dose of about 1 millisievert, the safety limit for exposure under normal standards (Ishizuka, 2011). On 14 December 2011, the Japanese Science Ministry assessed caesium fallout in Fukushima Prefecture in the four months after the March 11 disaster at 6.83 MBq/m2 – 94 % of which was concentrated in March, an indication of the severity of radiation discharge shortly after the onset of the accident (Asahi Shimbun, 2011).

Fallout attaches strongly, through ion exchange, to soil – in particular to clay soils common throughout Fukushima. From there the radiocaesium will move slowly into plants, at a rate, and level of risk, that remains unclear. Cs-137 strongly contaminated the soil in large areas of eastern and northeastern Japan, whereas western Japan was relatively sheltered by mountain ranges. The soils around the Fukushima nuclear site and neighboring prefectures have been extensively contaminated with depositions of more than 100 000 and 10 000 megabecquerel per square kilometre (MBq/km2), respectively (Yasunaria et al, 2011).

Correspondingly, it was reported that Fukushima Prefecture survey conducted in June and July 2011 found 33 Cs-137 hot-spots in excess of 1.48 MBq/m2, the level set by the Soviet Union for forced resettlement after the Chernobyl accident. A further 132 locations had combined Cs-137/134 of more than 0.555 MBq/m2, the level at which the Soviet authorities called for voluntary evacuation and imposed a ban on farming (Obe, 2011). Further reports suggest that radiation pollution is widely dispersed in Japan, with the Japanese Science Ministry confirming that Cs-134 and Cs-137 fallout was present in all prefectures, with the highest combined cumulative density of Cs-134 and Cs-137 found in Hitachinaka, Ibaraki Prefecture, at 0.0408 MBq/m2, followed by 0.0226 MBq/m2 in Yamagata, the capital of Yamagata Prefecture, and 0.0174 MBq/m2 in Tokyo's Shinjuku Ward (Ishizuka, 2011). Further reports indicated that the Japanese Environment Ministry estimated the contaminated zones at circa 2 400 km2 over Fukushima and four nearby prefectures, with Cs-134 and Cs-137 the dominant contaminants, mainly contained in the topsoil layer. By definition, shorter-lived isotopes decayed promptly (Reuters, 2011).

The Fukushima accident contaminated large areas of farmland and forests, albeit not as severely or extensively as at Chernobyl. But lacking land for resettlement and facing public outrage over the accident, the Japanese government has embarked on an unprecedented decontamination effort. The Japanese Ministry of the Environment estimates disposals of 15–31 million m3 of contaminated soil and debris by the time the decontamination projects finish (Bird, 2012). The total remediation programme may cover about 500 km2 where radiation dose levels are above 20 millisieverts per year (mSv/yr), and about 1 300 km2 where radiation dose levels are between 5 mSv/yr and 20 mSv/yr (IAEA, 2011a). In order to cope with this level of contamination, and in contradiction to international radiation protection standards, Japanese regulators have raised dose constraints to 20 mSv/yr – thereby subjecting schoolchildren to exposures normally only tolerated by adult nuclear workers.

Over the time of the accident, the amount of highly contaminated water on the site rose from 10 000 tonnes to 100 000 tonnes, presenting storage capacity difficulties (Reardon, 2011). The French Institute for Radiological Protection and Nuclear Safety estimated that between March and mid July, the amount of radioactive Cs-137 discharged into the Pacific from the Fukushima Daiichi plant amounted to 27.1 million megabecquerels - the greatest amount known to have been released to water from a single accident (Brumfiel and Cyranoski, 2011b).

Fukushima Dai-ichi Aftermath

The Japanese government established an independent Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company on June 7, 2011. The Committee's December 2011 Interim Report strongly criticized both central government and TEPCO, noting that both seemed unequal to the task of making decisions in order to stem radiation leaks as the situation at the coastal plant worsened in the days and weeks following the disaster. The Interim Report also noted that Japan's response to the crisis was flawed by poor communication and delays in releasing data on dangerous radiation leaks at the facility, and was critical of the regulatory authorities' 'inappropriate preparation' of nuclear disaster emergency planning (Investigation Committee, 2011).

In a commentary published in Nature, committee members Tomoyuki Taira and Yukio Hatoyama, both also members of the House of Representatives in the Japanese Diet, with Hatoyama having served as Prime Minister of Japan from 2009 until 2010, noted that their investigation had *"shown that key pieces of evidence remain incomplete… Particularly important is finding out whether the worst-case scenario occurred: that is, whether self-sustaining nuclear reactions were re-ignited in the core (re-criticality), creating more fission products and heat damage; whether the explosions that rocked the plant days after the earthquake were nuclear in origin, releasing radioactive metals from damaged fuel rods; and whether molten fuel has broken through the reactor's base, threatening environmental contamination"* (Tomoyuki and Hatoyama, 2011, p.313).

These internal critiques were compounded by others, questioning the relative independence of Japanese regulators: *"The Japanese government's main sources for scientific information for Fukushima were the industry ministry's Nuclear and Industrial Safety Agency and the Nuclear Safety Commission. Although these bodies might have expertise in nuclear reactor physics, they also have ties to the nuclear industry that create a conflict of interest. And they were not an effective and prompt source for quick decisions on decontamination or health risks"* (Nature, Editorial, 2011b).

Despite these ongoing difficulties, on 16 December 2012, the Japanese Prime Minister, Yoshihiko Noda, declared that the Fukushima nuclear plant had entered the state of cold shutdown; with cold shutdown confirmed by IAEA in their Status Report (IAEA, 2011)[4] . However, whilst the reactor temperatures had fallen, there still remained uncertainty about a series of ongoing problems, including the state and level of the nuclear fuel, particularly after confirmation that molten fuel may have eaten through three-quarters of the concrete under unit 1 and damaged the bases of two of the other reactors (TEPCO, 2012). A revised TEPCO timetable suggests that decommissioning, including melted reactor fuel, fuel rod removal, and repair of containment vessels, will take up to 40 years (ibid).

Extrapolating from monthly trade ministry data, the average Japanese nuclear power plant utilisation rate fell to 15.2 % in December 2011 from 67.9 % a year earlier (Reuters, 2012) and, following a further reactor shut-down in January 2012, to 10.3 % (Japan Times, 2012). With almost all of Japan's 54 reactors either offline in early 2012, or scheduled for shutdown, the issue of structural safety looms over any discussion about restarting them. Japan, traditionally a pro-nuclear country, derived about 30 % of its electricity from nuclear plants in 2010 – however opposition has been emerging as an important political issue, and the country's nuclear industry has been repositioning itself for a significantly less attractive market, halting plans to build 14 further reactors by 2030 (Crooks, 2011).

Although post-Fukushima plans for bio-monitoring and epidemiological assessment are still not finalised, it is clear that there will need to be a significant assessment of a wide range of environmental risk factors. Because some of the evacuees have started to settle across the country, long-term follow-up of the victims will need to account for geographic dispersion (Sugihara and Suda, 2011).

---

[4] 'Cold shutdown' normally refers to a state in which a reactor has become subcritical, with the temperature having been brought to a stable level below 95 ºC through the operation of normal systems.

Post-Fukushima Nuclear Policy Impact

Before the Fukushima accident, most planned nuclear power plant projects were in Asia and Eastern Europe, extending a trend from earlier years, including a dispersion of proposed new reactors around the Pacific seismic region. Between 2009 and April 2011 construction started on nine units; and where projects are going ahead, they do so with strong government support, including implicit or explicit public subsidy.

Nuclear Costs

A key challenge for nuclear power has been the high cost of construction (Davis, 2011). Nuclear new builds are high value and high risk construction projects with a marked tendency for significant delay and delay claims, cost growth and investor risk (KPMG, 2011). Based on the experiences of 52 United States investor-owned utilities that built nuclear power plants in1960-2011, the Texas Institute (2011) concluded that building nuclear power plants provide significant economic risks involving a 70 % certainty that a power utility would see borrowing costs rise due to the downgrading of credit rating once construction began, with plant construction marred by significant cost overruns and electricity tariff increases. Nuclear plants, which are among the largest and most complex engineering projects in the world, also carry high technical and regulatory risks, with World Nuclear Association figures showing very significant cost overruns for most projects, implying that utilities may only be able to pay for new plants if governments guarantee their income (Thomas, 2010a). Thus, costs and risks associated with nuclear construction may mean that plants may only be built with implicit and explicit public subsidy, including long-term power purchase agreements (Professional Engineering, 2011).

Since the Fukushima accident, the number of operating reactors fell from 441 at the beginning of 2011 to 435 in early 2012, with a total net installed capacity of just more than 368 gigawatts (GW), representing a decrease in installed nuclear capacity of around 10 GW or 3 %. Similarly, construction starts fell from 15 in 2010 to just 2 in 2011. New nuclear plant construction is progressing in Brazil, China, India, and Russia. Iran has recently completed its first reactor. New-build orders have been placed in the United Arab Emirates and the United States, with a planned call for tender in South Africa. Ordering continues in China, India, Korea and Russia.

In Europe, Finland and France are completing their new Generation III European Pressurized Reactor (EPR) at Olkiluoto and Flammanville, with the Finnish parliament and regulators having granted permits for construction of the country's sixth and seventh commercial reactors to Teollisuuden Voima (TVO) and Fennovoima (a subsidiary of E.ON), with a further reactor to be built at Olkiluoto by TVO. In October 2011, Fennovoima announced that it had chosen Pyhäjoki, in northern Finland, as a site for further nuclear expansion, with construction expected to start in 2015. Elsewhere, the United Kingdom's government, excluding Scotland, has in principle approved the concept of a new generation of up to eight nuclear power plants, subject to reactor generic design approvals; Bulgaria has begun detailed planning for a reactor at Belene; Romania has issued a planned call for tender; Poland's state utility, PGE, has shortlisted three sites as possible locations for their first nuclear power plant; and the Czech Republic is progressing with planning new-build – despite downsizing the proposed Temelin site tender from five to two reactors and Austria's strong objection to the expansion of the Temelin plant, which is situated near the border of the two countries.

Although Sweden formerly had a nuclear phase-out policy aiming to end nuclear power generation by 2010, on 5 February 2009, the Swedish Government announced an agreement allowing for the replacement of existing reactors. However, the Fukushima disaster may have reversed prior public support of nuclear power, with a BBC World Service - Globescan (2011) poll showing that 64 % of Swedes opposed new reactors while 27 % supported them. Similarly, whilst Spain has no plans for expansion or closure, public opposition to new nuclear build remains very high at 55 %. Whereas the United Kingdom is more favourable towards the use of nuclear energy than any other European country, with 37 % in favour of building new nuclear infrastructure (ibid).

Given that Germany uses around 20 % of all EU electricity, the government's March 2011 decision to close 7 of its 18 reactors, followed in June by the German Parliament vote to phase out nuclear power by 2022 and to invest in renewables, energy efficiency, grid network infrastructure, and plan for trans-boundary pumped-storage hydroelectricity (PSH), may prove significant for European energy policy as a whole. In June 2011, Italian voters also passed a referendum to cancel plans for new reactors, with over 94 % of the electorate voting in favour of the construction ban. Because 55 % of the eligible voters participated, the vote is binding. Elsewhere, six months after the Fukushima plant catastrophe, strong Swiss public opposition to nuclear led to a decision not to replace the countries five reactors when they come to the end of their operation in 2034. Belgium also confirmed a nuclear phase-out, with no firm date set for end of operation, whilst the only Dutch reactor at Borssele will remain open until 2033 if it can comply with the highest safety standards. It is also worth noting that, at a ministerial meeting in Vienna; ministers and heads of delegations of Austria, Greece, Ireland, Latvia, Liechtenstein, Luxembourg, Malta and Portugal, observed by ministers from Cyprus, Denmark and Estonia, concluded that nuclear power was not compatible with the concept of sustainable development, suggesting that nuclear power does not provide a viable option in combating climate change (Vienna Declaration, 2011).

Before Fukushima, the IAEA had predicted that around the world nuclear plants would add 360 GW of generating capacity by 2035, the equivalent of over 200 new reactors. Post-Fukushima, it has halved this forecast, partly due to diminishing public acceptance of nuclear energy, but also to the increased costs of nuclear security improvements and of insurance premiums for accident-related damages (Leveque, 2011). France has set radical safety standards for the industry. However the required plant upgrades are both technically difficult and expensive, with the French nuclear authority, ASN, estimating the cost of necessary improvements at the country's 58 nuclear reactors at around EUR 10 billion (Nature, Editorial, 2012).

Western European Nuclear Regulators Association (WENRA) 'Stress Tests' comprised a targeted reassessment of the safety margins of nuclear power plants in the light of Fukushima, including extreme natural events which challenge plant-safety functions, leading to severe accident (WENRA Task Force, 2011). However, since the European Nuclear Safety Regulators Group (ENSREG, 2011) decided that security issues were outside WENRA's remit, post-Fukushima stress tests of EU's 143 nuclear power reactors did not include accident and incident from an aeroplane strike or terrorist attack. The exclusion of these security issues seems unfortunate given that, for example, all UK civil nuclear infrastructures are uniquely implicated in all four tier-one threats identified in the UK National Security Strategy (HM Govt., 2010).

Despite further new-build plans in Finland, France and the United Kingdom; the general post-Fukushima situation in the EU implies that the limited construction of nuclear new-build since 2000, and potentially in the coming decade, combined with the ageing of nuclear power plants and the finalization of nuclear phase-out in Germany and other European countries, will lead to a relative decreasing share of electricity production sourced from EU nuclear energy after 2020. The emphasis is likely to shift towards maximizing output of existing reactors through extension, up-grade and retrofit (Leveque, 2011; Coenen and López, 2010).

The energy futures landscape within Europe is one of major national differences between state and market, choices and trade-offs over supply-side, demand-side, transmission and load-balancing infrastructure (Schiellerup and Atanasiu, 2011). Although EU states diverge in terms of cultural and industrial landscapes, public opinion, technological structures, institutions, regulatory practice and energy mixes, the European energy policy offers a fairly open and flexible framework in which some member states could develop collective action on energy issues. The development of sustainable and affordable low carbon energy remains a growing economic sector with huge potential for job creation (Andoura, 2010).

Cultural and Policy Diversity in Energy Governance

Finland: The Finnish discussion culture can be summarised as one in which decisions are preceded by an open public and policy debate, but once the decision has been made, according to the rules and regulations in force, there should no longer be room for complaints and further debate. Provided that proper procedures have been followed, changing course would mean loss of face and identity. Correspondingly, nuclear power has acquired the reputation of being the cheapest, safest, and most reliable source of electricity generation. This is primarily because there have been no serious nuclear accidents in Finland, and their reactors maintain a high reliability and load factor. These advantages are coupled with arrangements under the *Mankala Principle*, whereby large industrial corporations such as forest and heavy industry - as shareholders in nuclear power companies - can buy electricity at cost price (Lehtonen, 2010a; Lehtonen, 2010b).

Germany: Decisions on nuclear power cannot be separated from prior energy policy choices, and Germany has demonstrated a very strong, historic commitment to renewables, with renewable electricity production doubling between 1998 and 2003 and again between 2003 and 2008. By 2010 renewables contributed 17 % of total electricity production, and there are plans to increase this to at least 35 % by 2020 (BMU, 2011). Innovative German practice includes the first implementation of a fixed price feed-in-tariff, and huge purchases of solar photo voltaics (PV), which have driven down the world price of modules. Energy futures have also devolved to the local level, with communities securing political agreements under which the Bundesländer (federal states) are enabled to set goals and locations for renewable generation. This ensures that local energy resources and financial subsidies - paid for by customers (through feed-in tariffs), or taxpayers, (through cheap loans provided by the government development bank [KfW]) - benefit not only the energy companies but also the local people, with profits and employment kept in the region. Germany's non-nuclear energy policy is framed in the context of national pride and scientific-technological achievement, twinned with economic expansion: *"As the largest industrialized (European) nation, we can achieve a transformation toward efficient and renewable energy, with all the opportunities that brings for exports, and the development of new technologies and jobs"* (Chancellor Angela Merkel, in Gersman, 2011).

Nuclear Liability

The risk to people, the environment and to the future of nuclear energy as a consequence of a major incident is significant. The cost of the Chernobyl accident can only be roughly estimated, but a variety of government estimates from the 1990s put the cost of the accident, over two decades, at hundreds of billions of dollars.

More recent events at Fukushima tend to support the conclusion that reactor accidents may prove the single largest financial risk facing the nuclear industry, far outweighing the combined effect of market, credit, and operational risks. Perhaps unsurprisingly, liability estimates vary with ongoing events. Japanese replacement power costs in 2011 alone have been estimated at EUR 6.5 billion (JPY 700 billion), with decommissioning costs for the six reactors are estimated at EUR 9 billion (JPY 1 trillion). On May 20, 2011, TEPCO reported a net loss for the fiscal year ending in March 2011 of EUR 11.5 billion (JPY 1.25 trillion), the largest corporate loss in Japanese history outside the financial sector. By mid 2011, Bank of America Merrill Lynch reported that compensation claims could total EUR 93-102 billion (JPY 10–11 trillion) over the next two years, with liabilities far exceeding the current market cap (Maloney, 2011). By September 2011, Fukushima liabilities stood at anywhere between EUR 76-152 billion, with the Japanese Centre for Economic Research estimating clean-up remediation at EUR 190 billion over the next 10 years (Kobayashi, 2011).

Currently, individual European nuclear accident liabilities are capped at EUR 169 million for operators. However, the Paris Convention on Nuclear Third Party Liability and Brussels Convention (2011)[5] aims to raise this to ensure that victims of a nuclear incident are compensated for resulting damage. Under the proposals, nuclear operators would be liable for the first EUR 700 million for any accident, with the national government having the option of adding a maximum of a further EUR 500 million towards the company's liabilities. Collectively, other signatory states could contribute a further EUR 300 million, potentially bringing the total available to EUR 1 500 million for any one accident.

Yet actuarial analysis suggests that even this level of cover may fail to account for liability in case of major accident. Versicherungsforen Leipzig GmbH (2011), a company that specialises in actuarial calculations, concluded that these costs were not adequately internalised, suggesting that full insurance against nuclear disasters would increase the price of nuclear electricity by up to EUR 2.36 per kilowatt hour (kWh) – a sum that may weaken the economic case for nuclear power compared to other low-carbon sources.

Both the required liability (EUR 6.09 trillion), based on an estimate of the average maximum damage and corresponding variance, and the resulting insurance premium, are significantly higher than the financial resources currently legally required of nuclear power plant operators. Versicherungsforen Leipzig's study estimated that future damage and liability insurance costs would exceed the financial resources that nuclear power plant licensees are currently required to maintain by several orders of magnitude. In this context, nuclear disasters seem uninsurable, due to a combination of methodological difficulties in estimating the probability of occurrence of damage, insufficient size of the risk pool, and the extent of potential maximum damage (ibid).

To the extent that liability rules provide incentives for prevention, the financial limit on the liability of an operator may lead to under-deterrence – since, as a result of the financial cap on liability, the potential complementary function of liability rules in providing additional deterrence may be lost. The financial limit, and the resulting nuclear subsidy, may also distort competition by unduly favoring nuclear energy compared to other energy sources (Faure and Fiore, 2009).

The issue of nuclear waste liability has also been subject to intense and prolonged debate, especially in the context of high burn-up fuel proposed for Generation III reactors.

High Burn-up Fuel

Following the liberalisation of the EU energy market, it was realized that a decrease in nuclear costs could be achieved if reactor power could be optimized by using more uranium as reactor fuel and keeping the fuel rods in longer. This means that generation III reactor high burn-up spent fuel will be significantly more radioactive than conventional spent fuel. Five years after discharge, each square metre of spent fuel in the proposed EPR cooling ponds may generate up to 17 kW of heat compared with 11 kW from more conventional spent fuel pool. And the high density of spent fuel racks from the proposed Westinghouse AP 1000 reactor implies that 24-36 kW of heat may need to be removed from each square metre. Safety could depend on the effective and continuous removal of the significant thermal power of high burn-up spent fuel, potentially requiring additional pumps, back-up electricity supplies and back-up water supplies: all systems potentially vulnerable to mechanical failure or deliberate disruption. It is also likely that densely packed high burn-up spent fuel may require additional neutron absorbers, and greater radiation shielding during encapsulation and storage (Richards, 2009).

Nuclear Risk: Probabilistic Risk Assessment and Beyond Design-based Accidents

Key to the analysis of nuclear safety is the analytical concept of probabilistic risk assessment (PRA) or probabilistic safety analysis (PSA). Whilst PRA calculations are not taken as absolute, but rather as significant indicators of plant weaknesses, they do underpin the concept of acceptable risks and tolerable consequences under fault conditions. In this context, the risk of an accident must be acceptable, and the radiological consequences tolerable, with more frequently occurring incidents countered by greater resilience through enhanced safety systems grounded in robust engineered structures. However, PRA has proven structurally limited in its ability to conceive and capture the outcomes and consequences of a nuclear accident resulting from a cascading series of events, as described in the Fukushima disaster and all previous major nuclear accidents. This implies that relatively simplified chain-of-event fault-tree models may not be sufficient to account for the indirect, non-linear, and feedback relationships common for accidents in complex systems. Here, modeled common-cause, common-mode, and

---

[5] Note, not all EU states are signatories. Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Slovenia, Spain, Sweden, United Kingdom, Greece, Portugal and Turkey are signatories to the Paris Convention on Nuclear Third Party Liability and Brussels Convention.

dependent failures have proved problematic; partly due to data limitation (since major failures occur infrequently), and because failure mechanisms are often plant specific (Ramana, 2009).

Most PRAs assume failure likelihood can be captured through identical, independent log-normal failure distributions. Since strong independence assumptions employed in PRAs assume that reactor safety systems are dupli

cated and reliable, core damage frequency estimates are typically very low. Because of this, there may be good reason to question the conceptual and theoretical completeness, and empirical and practical reliability of PRA models. This is partly because PRA is prone to under-counting accident scenarios – since risk is estimated for enumerated reactor states, failure to account for unknown and serially cascading beyond design-base accident scenarios leaves an un-measurable model error in the core damage frequency estimate (Maloney, 2011).

Before the Fukushima accident, for example, the Japanese Nuclear Regulatory Commission Guidance (2006), updated in early 2011, concluded that *"robust sealed containment structures would prevent damage from a tsunami… and no radiological hazard would be likely"*. Whereas after the accident, the Chairman and President of the European Nuclear Society High Scientific Council stressed that *"the magnitude of the tsunami that struck Japan was beyond the design value to which the reactors were supposed to withstand"* (Bonin and Slugen, 2011). These pre and post-facto statements suggest that, although reactor design can prove relatively robust against specific accidents and specific modes, safety cannot be guaranteed for cascading beyond design-base accidents. In the case of Fukushima, because the cascade from earthquake, through tsunami, to reactor and spent fuel fault condition was discounted, no account was taken for the need to respond to the failure of three nuclear reactors and spent fuel ponds.

Pre-Fukushima probability estimates of a major nuclear accident were around 1:100 000 for the 440 reactors in operation over the next 20-25 years. Since Fukushima, estimated probabilities of major nuclear accidents have increased significantly. However, estimation of core melt and containment failure may still prove problematic. Chernobyl and Fukushima together comprise catastrophic meltdown in four nuclear reactors over the past few decades, implying that that the probability of a major accident in the current worldwide fleet over the next 20-25 years is around 1:5 000. Thus, whereas earlier estimates assumed a probability of one major nuclear accident over a 100-year period, reoccurrence of these events can be expected once every 20 years (Goldemberg, 2011). This reassessment of nuclear risk has been particularly apparent in Germany, where Chancellor Angela Merkel concluded that Fukushima *"has forever changed the way we define risk"* (Schwägerl, 2011); an analysis echoed by Norbert Röttgen, Germany's Environment Minister, who noted that Fukushima *"has swapped a mathematical definition of nuclear energy's residual risk with a terrible real-life experience… we can no longer put forward the argument of a tiny risk of 10-7, as we have seen that it can get real in a high-tech society like Japan"* (ibid).

Importantly, the governmental German Advisory Council on the Environment also concurred with this critique, suggesting that: *"The widespread view that the extent of the damage due even to major incidents can be adequately determined and limited in order to be weighed up… is becoming considerably less persuasive… The fact that the accident was triggered by a process which the nuclear reactor was not designed to withstand… casts a light on the limitations of technological risk assessment… based on assumptions, and that reality can prove these assumptions wrong"* (SRU, 2011b, p.11).

Levels of reliability required for a complex interactive and tightly coupled nuclear power plant are very great (Perrow, 1984), with the range of operating reactors having differing sets of designs and configurations. Because of their complexity and the physical conditions during reactor operation, the understanding of the reactor design and operation is always partial. Additionally, as system components and external events can interact in unanticipated ways, it is not possible to predict all possible failure modes. It follows that numerical estimates of probabilities of significant accidents remain deeply uncertain. As the Fukushima Investigation Committee concluded (2011, p. 22): *"The accidents present us (with) crucial lessons on how we should be prepared for… incidents beyond assumptions".*

Conclusion

Because it is likely that post-Fukushima health consequences may start to arise and be documented over the next 5-40 years, a key lesson to be learned concerns the multi-factorial nature of this event. It should also be understood that it is very unlikely that current major accident liability regimes will prove adequate, and a significant re-adjustment may be essential.

However, there seem to be no resounding new revelations over the vulnerability of nuclear power to unforeseen natural disasters like earthquakes and tsunamis, or through human or engineering based fault conditions, including accidental or deliberate harm. Accidents are by nature, accidental, and the cost of ignoring this common-sense axiom can prove radiologically catastrophic (Stirling, 2011).

Given the degree of uncertainty and complexity attached to even the most tightly framed and rigorous nuclear risk assessment, attempts to weight the magnitude of accident by the expected probability of occurrence has proven problematic, since these essentially theoretical calculations can only be based on sets of pre-conditioning assumptions. This is not an arcane philosophical point, but rather a very practical issue with significant implications for the proper management of nuclear risk. With its failure to plan for the cascade of unexpected beyond design-base accidents, the regulatory emphasis on risk-based probabilistic assessment has proven very limited. An urgent re-appraisal of this approach, and its real-life application seems overdue.

Whatever one's view of the risks and benefits of nuclear energy, it is clear that the possibility of catastrophic accidents must be factored into the policy and regulatory decision-making process. In the context of current collective knowledge on nuclear risks, both the regulation of operating nuclear reactors and the design-base for any proposed reactor will need significant re-evaluation.

Given the size of the long-term investments that are now needed across the options of nuclear, carbon based fuels, renewables, energy efficiency and conservation, grid network infrastructure development and load balancing; it is clear that European public needs to play a key role in taking these critical, social, environmental and economic decisions[6] . Here, public values and interests are central, and the role of public dialogue and the participatory practices that enable it are core to the building of mutual understanding between European states, governments, industry and people.

[6] The policy context of participatory governance concerning a shared, knowledge-based European Community energy future is set within the drive for sustainable development as located and expressed within in the EU's Lisbon Strategies of 2000, 2005, and 2009. These strategies are underpinned and operationalised by elements of the EU legislative framework, including the Directive on Public Participation in Environmental Plans and Programmes, the 2003 EU Public Participation Provisions of the Aarhus Convention, and the EU Directive on Strategic Environmental Assessment.

REFERENCES

Aghajanyan, A., Suskov, I. (2009): Trans-generational genomic instability in children of irradiated parents as a result of Chernobyl nuclear accident, Mutat. Res., 671: 52-57.

Andoura S. (2010): Energy Co-operation under the Aegis of the Weimar Triangle: Springboard for a Common European Energy Policy, Genshagener Papiere, Nr. 3, December 2010, Genshagen Foundation.

ARCH (Agenda for Research on Chernobyl Health) (2010): The Health Consequences of the Chernobyl Accident, Technical Report: http://arch.iarc.fr/documents/ARCH_TechnicalReport.pdf

Asahi Shimbun (2011): Fukushima radiation 47 times higher than combined 45 prefectures, Dec 15 2011, Asahi Shimbun: http://ajw.asahi.com/article/0311disaster/fukushima/AJ201112150025

Barber, R.C., et al. (2006) Radiation-induced trans-generational alterations in genome stability and DNA damage. Oncogene. 25: 7336-7342.

Barnham K. (2011): Nuclear risks and the renewable alternatives, The Guardian, Letters, Wednesday 16 March 2011:
http://www.guardian.co.uk/environment/2011/mar/16/nuclear-risks-and-renewable-alternatives

Baverstock, K. and Karotki, A.V. (2011) Towards a unifying theory of late stochastic effects of ionizing radiation. Mutat. Res., 718:1-9.

BBC Asia (2011): Radiation leak found outside Japan nuclear reactor, 28 March 2011:
http://www.bbc.co.uk/news/world-asia-pacific-12881015

BBC World Service, Globescan (2011): Opposition to Nuclear Energy Grows: Global Poll, http://www.globescan.com/news_archives/bbc2011_energy/

Bernard Bonin, Chairman of the ENS High Scientific Council, Vladimir Slugen,ENS President (2011): Statement on the Japanese Nuclear Accident, European Nuclear Society.

BfS (German Federal Office for Radiation Protection) (2008): Unanimous Statement by the Expert Group commissioned by the Bundesamt fur Strahlenschutz on the KiKK Study, Berlin, Germany 2007:

http://www.bfs.de/de/bfs/druck/Ufoplan/4334_KIKK_Zusamm.pdf

BIER VII Committee on the Biological Effects of Ionizing Radiations, US National Research Council (2006): Health effects of exposure to low levels of ionizing radiations, BEIR VII Phase 2, Washington.

Bird W. (2012): As Fukushima Cleanup Begins:
Long-term Impacts are Weighed, 9 Jan 2012, Report, Yale Environment 360, Yale School of Forestry
& Environmental Studies: fukushima_cleanup_begins_long-term_impacts_are_weighed/2482/

Bonin B. & Slugen V. (2011): Statement on the Japanese Nuclear Accident, European Nuclear Society (ENS) High Scientific Council, European Nuclear Society.

Bowyer, T.W., Biegalski, S.R., Cooper, M., Eslinger, P.W., Haas, D., Hayes, J.C., Miley, H.S., Strom, D.J., Woods, V., (2011): Elevated radioxenon detected remotely following the Fukushima nuclear accident. J. Environ. Radioact. 102: 681-687.

Brumfiel, G., Cyranoski, D. (2011a): Quake sparks nuclear crisis. Nature 471: 273-275.

Brumfiel, G., Cyranoski, D. (2011b): Fukushima deep in hot water
Rising levels of radioactive liquid hamper clean-up effort, 7 June 2011, Nature, 474: 135-136.

Brumfiel, G. (2011): Fallout forensics hike radiation toll: Global data on Fukushima challenge Japanese estimates, 25 October 2011, Nature, 478: 435-436.

Buongiorno J., Ballinger R., Driscoll M., Forget B., Forsberg C., Golay M., Kazima M., Todreas N., Yanch J. (2011): Technical Lessons Learned from the Fukushima-Daichii Accident and Possible Corrective Actions for the Nuclear Industry: An Initial Evaluation, Center for Advanced Nuclear Energy Systems, Nuclear Systems Enhanced Performance Program, MIT-NSP-TR-O25, Rev.1, 26 July 2011.

Bunn M. and Heinonen O. (2011): Preventing the Next Fukushima: Weak authority and largely voluntary standards limit global institutions' impact on nuclear safety and security, Science, Policy Forum, 16 Sept. 2011, Vol. 333: 1580-1581.

Butler, D. (2011): Radiation data from Japanese disaster starts to filter out, Nat. News 17 March 2011:
newscenter/news/tsunamiupdate01.html/.

Calmon, P., Thiry, Y., Zibold, G., Rantavaara, A., Fesenko, S., 2009. Transfer parameter Manolopoulou, M., Vagena, E., Stoulos, S., Ioannidou, A., Papastefanou, C. (2011): Radioiodine and Radiocesium in Thessaloniki, Northern Greece due to the Fukushima Nuclear Accident, J. Environ. Radioact., 102: 796-797.

Cardis E., Hatch M. (2011): The Chernobyl accident – an epidemiological perspective, Clin. Oncol., 23 (4): 251-260.

CERRIE (Committee Examining Radiation Risks of Internal Emitters) (2004): Report of the Committee Examining Radiation Risks of Internal Emitters, 2004, Crown Copyright, London.

Chernobyl Forum (2006): 2003-2005 Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the
Governments of Belarus, the Russian Federation and Ukraine, Second revised version, IAEA, Vienna.

Coenen L. and Díaz López F.J.D. (2010): Comparing systems approaches to innovation and technological change for sustainable and competitive economies: and explorative study into conceptual commonalities, differences and
Complementarities, Journal of Cleaner Production, 18: 1149□1160.

Crooks E. (2011): Nuclear: Enthusiasm for reactor investment cools, Financial Times, September 28, 2011.

Cyranoski D., & Brumfiel G (2011): Fukushima impact is still hazy, Nature. 2011, Sep 7: 477(7363): 139-40.

Davis L.W. (2011): Prospects for Nuclear Power, National Bureau of Economic Research, Working Paper 17674, Dec. 2011, National Bureau of Economic Research, http://www.nber.org/papers/w17674

DECC (Dept. of Energy and Climate Change) (2009): The Justification of Practices Involving Ionizing Radiation Regulations 2004: Consultation on the Secretary of State's proposed decisions as Justifying Authority on the Regulatory Justification of new nuclear power station designs known as the AP 100 and the EPR, London, The Stationary Office.

DECC (Dept. of Energy and Climate Change) (2010): The Justification of Practices Involving Ionizing Radiation Regulations 2004: The Reasons for the Secretary of State's Decision as Justifying Authority, London, The Stationary Office.

DECC (Dept. of Energy and Climate Change) (2011): Overarching National Policy Statement for Energy (EN-1), Planning for new energy infrastructure, July 2011, Presented to Parliament pursuant to section 5(9b) of the Planning Act 2008, London, The Stationery Office.

EEA (European Environment Agency) (1999): Children in their Environment: vulnerable, valuable, and at risk. Background paper by David Gee for the WHO Ministerial Conference on Environment and Health, London, June 16-18 1999.

EU (European Union) (2011): A Roadmap for moving to a competitive low carbon economy in 2050, Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions, COM/2011/0112 final, Brussels.
Ethics Commission on a Safe Energy Supply (2011): Germany's Energy

Turnaround, on behalf of Federal Chancellor Dr Angela Merkel, Berlin, 30 May, 2011.

EDF (Electricite de France) (2012): The low-carbon credentials of nuclear power:
http://www.edfenergy.com/energyfuture/the-possible-solutions-climate-change/nuclear-and-the-solution-climate-change

ENSREG (2011): EU Stress Tests specifications: http://www.ensreg.eu/node/289/
Evrard A-S., Hémon D., Morin A., Laurier D., Tirmarche M., Backe J-C., Chartier M., Clavel J. (2006): Childhood leukaemia incidence around French nuclear installations using geographic zoning based on gaseous discharge dose estimates, Br J Cancer, 2006 May, 94(9): 1342–7.

Faure M.G. & Fiore K. (2009): An Economic Analysis of the Nuclear Liability Subsidy, Pace Environmental Law Review, Pace University.

Gersman H. (2011): UK's faith in nuclear power threatens renewables, says German energy expert, The Guardian, Monday 28 November, 2011:
http://www.guardian.co.uk/environment/2011/nov/28/nuclear-uk-renewable-energy

Grigoriev Y.G (2012): Six first weeks after Chernobyl nuclear accident: Memoirs of an eyewitness, The Environmentalist, DOI: 10.1007/s10669-011-9384-z, Published On-line 29 Jan 2012: http://www.springerlink.com/content/x86p73j6233t7021/

Grigoriev Y.G. (2012): Personal communication to Paul Dorfman.

Goldemberg J. (2011): Oil Price:
http://oilprice.com/Alternative-Energy/Nuclear-Power/Have-Rising-Costs-and-Increased-Risks-Made-Nuclear-Energy-a-Poor-Choice.html

Günther B., Karau T,. Kastner E-M., Warmuth W. (2011): Calculating a risk-appropriate insurance premium to cover third-party liability risks that result from operation of nuclear power plants, Versicherungsforen Leipzig GmbH, Commissioned by the German Renewable Energy Federation (BEE)
Leipzig, 1 April 2011.

Hatch M., Ron E., Bouville, A., Zablotska L., Howe G. (2005): The Chernobyl disaster: cancer following the accident at the Chernobyl nuclear power plant, Epidemiol. Rev., 27: 56-66.

HM Government (2010): A Strong Britain in an Age of Uncertainty: The National Security Strategy, Presented to Parliament by the Prime Minister, October 2010, Cm. 7953, Stationery Office, London.

IAEA (International Atomic Energy Agency) (2000): Climate Change and Nuclear Power, IAEA, Austria.

IAEA (International Atomic Energy Authority) (2011a): Final Report of the International Mission on Remediation of Large areas Offsite the Fukushima Dai-ichi NPP, 7-15 Oct 2011, NE/NEF FW/2011, IAEA.

IAEA (International Atomic Energy Authority) (2011b): Fukushima Daiichi Status Report, 22 December 2011.
http://www.iaea.org/newscenter/focus/fukushima/statusreport221211.pdf

IAEA (International Atomic Energy Authority) (2011c): Investigation Committee (2011): Interim Report, Investigation Committee on the Accidents at Fukushima Nuclear Power Stations of Tokyo Electric Power Company, December 26, 2011, IAEA.

ICRP (International Commission on Radiological Protection) (2005): Low-dose Extrapolation of Radiation-related Cancer Risk, ICRP Publication 99, Ann. ICRP, 35(4), ICRP.

IPCC (Intergovernmental Panel on Climate Change)(2011): IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Investigation Committee (2011): Investigation Committee on the Accidents at Fukushima Nuclear Power Stations of Tokyo Electric Power Company, Executive Summary of the Interim Report, Provisional, December 26, 2011.

Ishizuka H. (2011): Cesium from Fukushima plant fell all over Japan, November 26, 2011, Asahi Shimbun
http://ajw.asahi.com/article/0311disaster/fukushima/AJ201111260001

Ivanov V.K., Gorsky A.I., Kashcheev V.V., Maksiutov M.A., Tumanov K.A. (2009): Latent period in induction of radiogenic solid tumors in the cohort of emergency workers, Rad. Environ. Biophys., 2009, 48: 247-252

Iwanaga M., Hsu W.L., Soda M., Takasaki Y., Tawara M., Joh T., Amenomori T., Yamamura M., Yoshida Y., Koba T., Miyazaki Y., Matsuo T., Preston D.L., Suyama A., Kodama K., Tomonaga M. (2011): Risk of myelodysplastic syndromes in people exposed to ionizing radiation: a retrospective cohort study of Nagasaki atomic bomb survivors, J. Clin. Oncol. 2011 Feb 1, 29 (4): 428-34.

Jablon S., Hrubec Z., Boice J.D. (1991): Cancer in populations living near nuclear facilities, Report of a survey by researchers at the US National Cancer Institute, Journal of the American Medical Association, 265: 1403-1408.

Japan Times (2012): Nuclear plant output falls to 10.3%, Saturday, Jan. 14, 2012, http://www.japantimes.co.jp/text/nn20120114n1.html

Kaatsch P., Spix C., Schmiedel S., Schulze-Rath R., Mergenthaler A., Blettner M. (2007): Epidemiologische Studie zu Kinderkrebs in der Umgebung von Kernkraftwerken (KiKK-Studie). Zusammenfassung.

Kaatsch P., Spix C, Schulze-Rath R, Schmiedel S and Blettner M (2008a). Leukaemia in young children living in the vicinity of German nuclear power plants, Int. J. Cancer, 122: 721–726.

Kaatsch P., Spix C., Jung I. and Blettner M. (2008b). Childhood leukemia in the vicinity of nuclear power plants in Germany, Dtsch. Arztebl. Int., 105: 725-732.

Kadhim, M.A., et al. (1992) Transmission of chromosomal instability after plutonium alpha-particle irradiation, Nature, 355: 738-740.

Kinlen L (2011). Childhood leukaemia, nuclear sites, and population mixing. Br. J. Cancer, 104: 12–18.

Kobayashi T. (2011): Nuclear Generating Cost Treble Pre-Accident Level: Huge Price Tag on Fukushima Accident Cleanup, Japanese Centre for Economic Research, July 19, 2011.

Kopytko N. & Perkins J. (2011): Climate change nuclear power, and the adaptation-mitigation dilemma, Energy Policy, Vol. 39, Issue 1: 318-333.

Kostenko, T.A. (2005): Evolution of cardiovascular disorders in remote period after Chernobyl accident in children and adolescent evacuated from Zhitomir area, Int. J. Rad. Med., 7: 1-4.
http://www.physiciansofchernobyl.org.ua/magazine/PDFS/7_2005/Kostenko.pdf

KPMG (2011): Construction Risk in new Nuclear Power Projects - Eyes Wide Open, KPMG International.

Large J (2011a): Fukushima: 'Lessons Learned' for Nuclear New Build: Implications for world-wide nuclear regulatory regimes – specific application to Europe and UK, Keynote Seminar, Westminster, Committee Room 11, London.

Large J. (2011b): Update on the Nuclear and Radiological Situation at Fukushima Dai-ichi., R3197-AR1, 24 May 2011.

Larsen, PR., Canand RA., Knudsen, K. (1982): Thyroid hypofunction after exposure to fallout from a hydrogen bomb explosion JAMA, 1982, 247: 1571-1574.

Lehtonen M. a. (2010): Opening Up or Closing Down Radioactive Waste Management Policy? Debates on Reversibility and Retrievability in Finland, France, and the United Kingdom, Risk, Hazards & Crisis in Public
Policy, 1: 4, Article 6.

Lehtonen M. b. (2010): Deliberative decision-making on radioactive waste management in Finland, France and the UK: influence of mixed forms of deliberation in the macro discursive context, Journal of Integrative Environmental Sciences, Vol. 7, No. 3, September 2010: 175–196.

Leveque F. (2011): Nuclear outlook in the EU by 2020 and beyond, Energy Policy Blog, June 18 2011:
http://www.energypolicyblog.com/2011/06/18/nuclear-outlook-in-the-eu-by-2020-and-beyond/#more-1983

Lorimore S.A, Mukherjee D., Robinson J.I., Chrystal J.A., Wright E.G. (2011): Long-lived Inflammatory Signaling in Irradiated Bone Marrow is Genome Dependent, Cancer Research 71: 6485-6491, Published OnlineFirst September 8, 2011.

Lozano RL, Hernández-Ceballos MA, Adame JA, Casas-Ruíz M, Sorribas M, San Miguel EG, Bolívar JP. (2011): Radioactive impact of Fukushima accident on the Iberian Peninsula: evolution and plume previous pathway, Environ Int. 2011 Oct; 37(7): 1259-64. E pub. 2011, Jun 16.

Maloney S. (2011): Assessing nuclear risk in the aftermath of Fukushima, Energy Risk, 11 Jul, 2011.

Marais K, Dulac N, Leveson N. (2004): Beyond normal accidents and high reliability organizations: the need for an alternative approach to safety in complex systems. Presented at MIT Eng. Syst. Symp. Mar. 29–31, Cambridge, MA.

Manolopoulou, M., Vagena, E., Syoulos, S., Loannidou, A., Papastefanou, C., (2011): 213 Radioiodine and radiocesium in Thessaloniki, Greece due to the Fukushima 214 nuclear accident. J. Environ. Radioactiv. 102(8): 796-797.

Marshall E., & Reardon S. (2011): How Much Fuel Is at Risk at Fukushima? Science, 17 March 2011:
http://news.sciencemag.org/scienceinsider/2011/03/how-much-fuel-is-at-risk-at-fukushima.html

McCarthy, M. (1997): Nuclear bomb test fallout may cause many US cancers, The Lancet, 1997, 350 (9075): 415.

Minoura, K., F. Inamura, D. Sugawara, Y. Kono, T. Iwashita (2001): The 869 Jgan tsunami deposit and recurrence interval of large-scale tsunami on the Pacific coast of northeast Japan, Journal of Natural Disaster Science, Vol. 23, 2: 83-88.

Mukherjee D., Coates P.J., Lorimore S.A, Wright E.G. (2012): The In Vivo Expression of Radiation-Induced Chromosomal Instability Has an Inflammatory Mechanism, Radiation Research, 177: 18–24.

Nagasawa, H. and Little J.B. (1992): Induction of sister chromatid exchanges by extremely low doses of alpha-particles, Cancer Research, 52: 6394-6396.

Nagataki S, Shibata Y, Inoue S, Yokoyama N, Izumi M, Shimaoka K. (1994): Thyroid diseases among atomic bomb survivors in Nagasaki, Radiation Effects Research Foundation, Nagasaki, Japan, Aug 3, 272(5): 364-70.

Nagataki, S., Nystrom, E. (2002): Epidemiology and primary prevention of thyroid cancer Thyroid, 12(10): 889-896.

Nature, Editorial (2011a): A little knowledge, Nature, 472: 135, 14 April 2011, Published online 13 April 2011: http://www.nature.com/nature/journal/v472/n7342/full/472135a.html?WT.ec_id=NATURE-20110414

Nature, Editorial (2011b): Critical Mass, Nature, December 2011, Vol. 480: 291:
http://www.nature.com/nature/journal/v480/n7377/full/480291a.html

Nature, Editorial (2012): Get tough on nuclear safety: A refreshingly frank and forward-looking report on the safety of French nuclear power plants in the wake of Fukushima should spur other countries to take a hard look at regulation of their own reactors, Nature, 481: 113, 12 January 2012.

NIA (Nuclear Industry Association) (2012): NIA challenges WWF and Greenpeace 'subsidy' claim, Govtoday:
http://www.govtoday.co.uk/index.php/Nuclear-Energy/nia-challenges-wwf-and-greenpeace-subsidy-claim.html

Noshchenko A.G., Bondar O.Y., Drozdova V.D. (2010): Radiation-induced leukemia among children aged 0-5 years at the time of the Chernobyl accident. Int. J. Cancer.,15: 127(2): 412-26.

Obe M. (2011): Japan Finds Radiation Spread Over a Wide Area, Wall St. Journal Asia, Asia News, August 31, 2011.

Pacini, F., Vorontsova, T., Molinaro, E., Kuchinskaya, E., Agate, L., Sharova, E., Astachova, L., Chiovato, L., Pinchera, A. (1999): Radiation and thyroid autoimmunity., Int J Rad Med., 3(3-4): 20-24.

Paris Convention (2011): Protocols to Amend the Brussels Supplementary Convention on Nuclear Third Party Liability, No. 26, February, 2011.

Park J (2011): Earthquake 9.0: What this magnitude might mean for Japan's future, Bulletin of Atomic Scientists, 16 March, 2011
http://www.thebulletin.org/web-edition/features/earthquake-90-what-magnitude-might-mean-japans-future

Peplow M. (2001): Chernobyl's legacy: Twenty-five years after the nuclear disaster, the clean-up grinds on and health studies are faltering. Are there lessons for Japan? 28 March 2011, Nature, 471: 562-565.

Perrow C. (1984): Normal Accidents: Living With High Risk Technologies. (Revised edition, 1999). Princeton, NJ: Princeton University Press.

Perrow C. (2011): The Next Catastrophe: Reducing Our Vulnerabilities to Natural, Industrial, and Terrorist Disasters, 21 Feb 2011, Princeton University Press.

Preston D.L., Shimizu Y. et al (2003): Studies of mortality of atomic bomb survivors: solid cancer and no-cancer disease mortality: 1950-1997, Radiation Research, Vol. 160: 381-407.

Professional Engineering (2011): Questions over funding for nuclear expansion: Costs and risks associated with nuclear construction raise further questions, 3 October 2011, Professional Engineering:
http://profeng.com/news/questions-over-funding-for-nuclear-expansion

Rahu, M., Tekkel, M., Veidebaum, T., Pukkala, E., Hakulinen, T., Auvinen, A., Rytomaa, T., Inskip, PD., Boice, JD. (1987): The Estonian study of Chernobyl cleanup workers: II Incidence of cancer and mortality, Radiat. Res., 147 (5): 653-675.

Ramana M.V. (2009): Nuclear Power: Economic, Safety, Health, and
Environmental Issues of Near-Term Technologies, Annual Review Environment Resources, 34: 127-52.

Reardon, S. (2011): Fukushima radiation creates unique test of marine life's hardiness, Science, 332: 292.

Reuters (2011): IAEA experts to help in Japan nuclear clean-up, Oct 4, 2011.

Reuters (2012): Japan Dec nuclear plant usage at 15.2% vs. 67.9% a year ago, Tokyo, Tue Jan 10, 2012. Reuters:
http://uk.reuters.com/article/2012/01/10/nuclear-japan-utilisation-idUKT9E7N702320120110

Richards H. (2009): Spent Nuclear Fuel - the Poisoned Chalice: A Paper for the Nuclear Consultation Group, March 2009:
http://www.nuclearconsult.com/docs/information/waste/Spent_Nuclear_Fuel–the_Poisoned_Chalice.pdf

Romanenko A.Y., Finch S.C., Hatch M., Lubin J.H., Bebeshko V.G., Bazyka D.A., Gudzenko N., Dyagil I.S., Reiss R.F., Bouville A., Chumak V.V., Trotsiuk N.K., Babkina N.G., Belyayev Y., Masnyk I., Ron E., Howe G.R., Zablotska L.B. (2008): The Ukrainian-American study of leukemia and related disorders among Chernobyl cleanup workers from Ukraine: III. Radiation risks. Radiat. Res. 170(6): 711-20.

Schwägerl C. (2011): Germany's Unlikely Champion
of a Radical Green Energy Path, Yale Environment 360, University of Yale, School of Forestry and Environmental Studies.
http://e360.yale.edu/feature/germanys_unlikely_champion_of_a_radical_green_energy_path/2401/

Sermage-Faure S., Laurier D., Goujon-Bellec D., Chartier M., Goubin A., Rudant J., Hemon D., Clavel J. (2012): Childhood leukemia around nuclear power plants French - the study GeoCAP, 2002-2007, International Journal of Cancer, Article Accepted (Accepted, unedited articles published online for future issues):
http://translate.googleusercontent.com/translate_c?hl=en&prev=/search%3Fq%3DIRSN%2BFrance%26hl%3Den%26client%3Dsafari%26rls%3Den%26prmd%3Dimvnsu&rurl=translate.google.co.uk&sl=fr&u=http://onlinelibrary.wiley.com/doi/10.1002/ijc.27425/abstract&usg=ALkJrhgVSt12M1MuHvwTSJYqHNTk4EeDBQ

Shershakov V., Kosyh V. (2011): Information Support System for Decision-making in Case of Emergencies Leading to Environmental Pollution: Its Development and Implementation in the Research and Production, Association Typhoon, Roshydromet.

Shimizu, Y., Kato, H., Schull, WJ. (1991): Risk of cancer among atomic bomb survivors, J. Rad. Res. Suppl. 2: 54-63.

Shimizu Y., Kodama K., Nish, N., Kasagai F., Suyama A., Soda M., Grant, E.J., Sugiyama H., Sakata R., Moriwaki H., Hayashi M., Konda M., Shore R.E. (2010): Radiation exposure and circulatory disease risk: Hiroshima and Nagasaki atomic bomb survivor data, 1950-2003., BMJ: 340: 5349.

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

SRU (German Advisory Council on the Environment) (2011a): Pathways towards a 100% renewable electricity system: Summary for policy makers, SRU, Berlin.

SRU (German Advisory Council on the Environment), Faulstich M., Foth H., Calliess C., Hohmeyer O., Holm-Müller K., Niekisch M. (2011b): Pathways towards a 100 % renewable electricity system, Special Report, Oct 2011, SRU, Berlin.

Stirling A. (2011): Neglected Nuclear lessons, STEPS (Social, Technological and Environmental Pathways to Sustainability), University of Sussex:
http://stepscentre-thecrossing.blogspot.com/2011/03/japan-neglected-nuclear-lessons.html

Stohl A.P, Seibert G., Wotawa D., Arnold J. F., Burkhart S., Eckhardt C., Tapia A., Vargas, Yasunari T. J. (2011): Xenon-133 and caesium-137 releases into the atmosphere from the Fukushima Dai-ichi nuclear power plant: determination of the source term, atmospheric dispersion, and deposition, Atmos. Chem. Phys. Discuss., 11: 28319-28394:
www.atmos-chem-phys-discuss.net/11/28319/2011/ doi:10.5194/acpd-11-28319-2011, Atmospheric Chemistry.

Sugihara G, Suda S. (2011): Need for close watch on children's health after Fukushima disaster, Aug, 6:378 (9790): 485-6.

TEPCO (Tokyo Electric Power Company) (2012): Current Status of Fukushima Daiichi and Fukushima Dai-ichi Nuclear Power Station, December 16, 2011, TEPCO.
http://www.tepco.co.jp/en/nu/fukushima-np/f1/images/f12np-gaiyou_e_2.pdf

Yasunaria T.J., Stohlb A., Hayanoc R.S., Burkhartb J.F., Eckhardt S., Yasunarie T. (2011): Cesium-137 deposition and contamination of Japanese soils due to the Fukushima nuclear accident, PNAS 2011 108 (49): 19530-19534; published ahead of print November 14, 2011.

Texas Institute (2011): Impact of nuclear power projects on credit ratings and creditor recoveries following default of investor owned utilities sponsoring nuclear projects, Research Study, Sept. 1 2011, Texas Institute.

Thomas S. (2010a): The Economics of Nuclear Power: An Update, Heinrich-Böll-Stiftung, Berlin: http://www.boell.de/downloads/ecology/Thomas_economics.pdf

Thomas S. (2010b): Really, Mr Huhne, you should brush up on your French, Parliamentary Brief, Online, 1 September 2010: http://www.parliamentarybrief.com/2010/09/really-mr-huhne-you-should-brush-up-on-your-french

Thomas S. (2010c): The EPR in Crisis, PSIRU, University of Greenwich: http://www.psiru.org/publications?type=report

Thomas S. (2011): New thinking now needed for Nuclear: Public interest in Britain's plans for new nuclear power plants, Parliamentary Brief, Online, 04 April 2011:
http://www.parliamentarybrief.com/2011/04/new-thinking-now-needed-for-new-build-nuclear#all

Timoshevski A.A., Kalinina N.M., Grebenyuk A.N. (2011): The state of immunity in the liquidators of consequence of the Chernobyl accident with cardiovascular disease, Radiates. Biol. Radioecol., 2011, 51(1): 178-184.

Tomoyuki Taira T., Hatoyama Y. (2011): 'Nationalise the Fukushima Daiichi atomic plant: Only by bringing the nuclear power station into government hands can scientists find out what really happened', Nature, Comment, 15 December 2011, 480: 313-314.

UNDP, UNICEF, UN-OCHA & WHO (2002): The Human Consequences of the Chernobyl Nuclear Accident: A Strategy for Recovery, A Report Commissioned by UNDP and UNICEF with the support of UN-OCHA and WHO, 22 January 2002.

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) (2008): Sources and effects of ionizing radiation, Vol. II, UN, Report to the General Assembly with Scientific Annexes, New York.

Vienna Declaration (2011): Declaration, May 25, 2011, Vienna, Ministers and Heads of Delegations of Austria, Greece, Ireland, Latvia, Liechtenstein,
Luxembourg, Malta and Portugal, Lebensministerium.

Warren A. (2011): Thirty years on and still waiting for an answer: Why does Germany expect to cut electricity consumption while the UK foresees demand doubling? It's because the UK still hasn't done the analysis, The Warren Report, Energy in Buildings in Industry (EIBII), Feb 2011, p.12.

WENRA Task Force (2011): 'Stress tests' Specifications, Proposal by the WENRA Task Force, 21 April 2011.

WNA (World Nuclear Association (2012): Nuclear Energy and Climate Change, http://www.world-nuclear.org/climatechange/

WHO Expert Group (2006): Health Effects of the Chernobyl Accident and Special Health Care Programmes: Report of the UN Chernobyl Forum Health Expert Group, Editors Burton Bennett, Michael Repacholi and Zhanat Carr, World Health Organization, Geneva, 2006.

Yablokov A., Lablunska I., Blokov I. (Eds.) (2006): The Chernobyl Catastrophe - Consequences on Human Health: The difficult truth about the Chernobyl catastrophe: the worst effects are still to come, April 18, 2006, Greenpeace, Amsterdam.

Yablokov A., Vassily B., Nesterenko A.V. (2007): Chernobyl: Consequences of the Catastrophe for People and the Environment, Annals of the New York Academy of Sciences, Annals of the New York Academy of Sciences.

Yamada M., Wong F.L., Fujiwara S., Akahoshi M., Suzuki G. (2004): Non-cancer disease incidence in atomic bomb survivors, 1958-1998, Rad. Res., 161/69: 622-632.

Yi-chong X. (Ed.) (2011): Nuclear Development in Asia, Problems and Prospects, Palgrave Macmillan, New York.

Yoshida K., Nakachi K., Imai K., Cologne J.B., Niwa Y., Kusunoki Y., Hayashi T. (2009): Lung cancer susceptibility among atomic bomb survivors in relation to CA repeat number polymorphism of epidermal growth factor receptor gene and radiation dose, Carcinogenesis, 30(12): 2037-2041.

Yoshimoto Y., Yoshinaga S., Yamamoto K., Fijimoto K., Nishizawa K., Sasaki Y. (2004): Research on potential radiation risks in areas with nuclear power plants in Japan: leukaemia and malignant lymphoma mortality between 1972 and 1997 in 100 selected municipalities, J. Radiol. Prot. 24; 343-368.

Zheng J., Tagami K., Watanabe Y., Uchida S., Aono T., Ishii N., Yoshida S., Kubota Y., Fuma S., Ihara S. (2012): Isotopic evidence of plutonium release into the environment from the Fukushima DNPP accident, Scientific Reports:
http://www.nature.com/srep/2012/120308/srep00304/full/srep00304.html

WISE/NIRS NUCLEAR MONITOR

The Nuclear Information & Resource Service was founded in 1978 and is based in Washington, US. The World Information Service on Energy was set up in the same year and houses in Amsterdam, Netherlands. NIRS and WISE Amsterdam joined forces in 2000, creating a worldwide network of information and resource centers for citizens and environmental organizations concerned about nuclear power, radioactive waste, radiation, and sustainable energy issues.

The WISE/NIRS Nuclear Monitor publishes international information in English 20 times a year. A Russian version is published by WISE Russia and a Ukrainian version is published by WISE Ukraine. The WISE/NIRS Nuclear Monitor can be obtained both on paper and in an email version (pdf format). Old issues are (after two months) available through the WISE Amsterdam homepage: www.wiseinternational.org
Receiving the WISE/NIRS Nuclear Monitor

US and Canada based readers should contact NIRS for details of how to receive the Nuclear Monitor (address see page 19). Others receive the Nuclear Monitor through WISE Amsterdam.
For individuals and NGOs we ask a minimum annual donation of 100 Euros (50 Euros for the email version). Institutions and industry should contact us for details of subscription prices.

WISE AMSTERDAM/NIRS

ISSN: 1570-4629

Editorial team: Peer de Rijk

The “Elfi Gmachl Foundation for a Nuclear-free Future” / PLAGE-Salzburg supports the Nuclear Monitor financially.
See: http://www.plage.cc (not available in English (yet))

WISE/NIRS offices and relays

WISE Amsterdam
P.O. Box 59636
1040 LC Amsterdam
The Netherlands
Tel: +31 20 612 6368
Fax: +31 20 689 2179
Email: wiseamster@antenna.nl
Web: www.antenna.nl/wise

NIRS
6930 Carroll Avenue, Suite 340
Takoma Park, MD 20912
Tel: +1 301-270-NIRS
(+1 301-270-6477)
Fax: +1 301-270-4291
Email: nirsnet@nirs.org
Web: www.nirs.org

NIRS Southeast
P.O. Box 7586
Asheville, NC 28802
USA
Tel: +1 828 675 1792
Email: nirs@main.nc.us

WISE Argentina
c/o Taller Ecologista
CC 441
2000 Rosario
Argentina
Email: wiseros@ciudad.com.ar
Web: www.taller.org.ar

WISE Austria
WISE Austria
c/o atomstopp
Roland Egger
Promenade 37
4020 Linz
Tel: +43 732 774275
Fax: +43 732 785602

WISE Czech Republic
c/o Jan Beranek
Chytalky 24
594 55 Dolni Loucky
Czech Republic
Tel: +420 604 207305
Email: wisebrno@ecn.cz
Web: www.wisebrno.cz

WISE India
42/27 Esankai Mani Veethy
Prakkai Road Jn.
Nagercoil 629 002, Tamil Nadu
India
Email: drspudayakumar@yahoo.com;

WISE Japan
P.O. Box 1, Konan Post Office
Hiroshima City 739-1491
Japan

WISE Russia
Moskovsky prospekt 120-34
236006 Kaliningrad
Russia
Tel/fax: +7 903 299 75 84
Email: ecodefense@rambler.ru
Web: www.anti-atom.ru

WISE Slovakia
c/o SZOPK Sirius
Katarina Bartovicova
Godrova 3/b
811 06 Bratislava
Slovak Republic
Tel: +421 905 935353
Email: wise@wise.sk
Web: www.wise.sk

WISE South Africa
c/o Earthlife Africa Cape Town
Maya Aberman
po Box 176
Observatory 7935
Cape Town
South Africa
Tel: + 27 21 447 4912
Fax: + 27 21 447 4912
Email: coordinator@earthlife-ct.org.za
Web: www.earthlife-ct.org.za

WISE Sweden
c/o FMKK
Tegelviksgatan 40
116 41 Stockholm
Sweden
Tel: +46 8 84 1490
Fax: +46 8 84 5181
Email: info@folkkampanjen.se
Web: www.folkkampanjen.se

WISE Ukraine
P.O. Box 73
Rivne-33023
Ukraine
Tel/fax: +380 362 237024
Email: ecoclub@ukrwest.net
Web: www.atominfo.org.ua

WISE Uranium
Peter Diehl
Am Schwedenteich 4
01477 Arnsdorf
Germany
Tel: +49 35200 20737
Email: uranium@t-online.de
Web: www.wise-uranium.org

TPG Post
Port betaald

WISE/NIRS NUCLEAR MONITOR

c/o WISE Amsterdam
PO Box 59636
1040 LC Amsterdam
Netherlands

PRINTED MATTER
MATIERE IMPRIME

PRIORITY
PRIORITAIRE