The 25th Anniversary of the Chernobyl Accident

Phil Simmons[1]

School of Economics, Business & Public Policy, University of New England, Armidale, AUSTRALIA, 2350

The nuclear accident at the Chernobyl plant in 1986 is described and a summary of its immediate effects on people and the environment outlined. Then there is a summary of the important parts of the literature on diseases and deaths resulting from radiation and mortalities to date and the way mortality data became increasingly conservative over the years is discussed. Today, there is still uncertainty about future mortalities dues to long latency periods for many cancers however cancer deaths in Chernobyl affected regions are expected to be similar to non-Chernobyl controls. The major literature on environmental effects on wild species, forests, water and agricultural land are then reported with a brief discussion of remediation work and of current trends. Finally, contemporary perceptions of the Chernobyl accident are described in the context of popular anti-nuclear sentiment that prevailed in 1986, the immense publicity surrounding the accident and the natural tendency of people to exaggerate prospects of unlikely, yet extreme, events.

Contributed Paper to the 55th Annual Australian Agricultural and Resource Economics Society Conference, Crown Conference Centre, Southbank, Melbourne, Victoria, 8-11th February, 2011

[1] The author has no conflict of interest

1. Back ground

Recently, an acquaintance told me his daughter had been diagnosed with thoracic cancer and had undergone an operation. She is in her late twenties and grew up on a farm in Wales. Her doctors had informed her that this was certain to be a 'Chernobyl cancer'. This news prompted me to read some of the literature on the Chernobyl accident and its aftermath. After 25 years, Chernobyl still looms like a spectre over the nuclear industry and seems to be playing too important a role in contemporary debate over nuclear power for an event that occurred so long ago.

The Chernobyl accident began on the 26th of April 1986 as a result of an ill-judged experiment disabling safety devices when the plant was shut down. A steam explosion blew a reactor apart releasing radioactive gases. Graphite in the exposed core caught fire and burned for ten days despite efforts to extinguish the blaze (Anspaugh, 2008). This fire released radio-nuclides as aerosols and fuel particles into the atmosphere. The reactor was an older style RBMK type that did not have a protective shield to capture escaped gases and particles as modern reactors do. Due to bureaucratic secrecy, firemen were not informed of the dangers and some of those on duty who initially dealt with the fire suffered severe radiation burns. As the days went by, stories of individual heroism and self sacrifice emerged while the number of deaths increased. By the time the fire was extinguished, there were 30 deaths, 28 from radiation sickness WHO (2006).

By the end of May 1986 it was clear that damage to the urban, natural, agricultural, forest and aquatic environments was extending beyond the area immediately surrounding the plant, ultimately affecting 200,000 square kilometers of European territory. Seventy one per cent of this contamination fell in three countries, Ukraine, where the reactor was located, Belarus and Russia. The deposits were uneven with Radiocaesium spread widely, accounting for 200,000 square kilometer figure above, while most of the Strontium and Plutonium, heavier particles, fell within 100km of the reactor. Much of the release was comprised of radionuclides with short half lives so many have decayed by today. Radioactive iodine, with a half life of eight days, was a concern immediately after the accident and responsible for thoracic cancers with latent ones still being diagnosed today. Caesium and Strontium were the important contaminants for the next few years, then Plutonium and 241Am, with half lives in thousands of years, became long term concerns (Anspaugh, 2008).

Losses arising from Chernobyl can be categorized in a number of ways. The most poignant, and most easily understood, losses are to human life. These losses are discussed in detail in the next section. ElBaradei (2008) reported 50 emergency workers died from acute radiation syndrome in 1986 or due to other, related, illnesses later. About 4000 children and adolescents were diagnosed with thyroid cancer from radioactive iodine in food with 15 of those dying. ElBaradei reports that eventually a total around 4000 deaths will be attributed to the Chernobyl accident. All of these figures are highly controversial and discussed in the next section in more detail.

Psychosocial impacts are now recognized as being underestimated in the decade following the Chernobyl accident, with impacts on three groups: evacuees, liquidators and those who continued to live in contaminated areas. Gerasimova (2008) argues 'the severest consequences [for Russia] of the Chernobyl accident have been social in nature and are not as a consequence of radiological events'. 116,000 people were evacuated from villages around Chernobyl in 1986, with total evacuees from severely contaminated areas eventually reaching 335,000 (WHO, 2006). Most of these people did not return to their original homes and later suffered from depression and stress related difficulties. In 1986 and 1987 residual mitigation activities were undertaken and around 240,000 workers (liquidators) recruited. Eventually 600,000 people received special certificates confirming their status as liquidators (UNSCEAR, 2000). Danzon (2008) reports 'Exposed populations have anxiety levels that are twice as high as controls and they are 3-4 times more likely to report multiple, unexplained physical symptoms and subjective poor health than unaffected control groups.'

Nuclear power remains controversial and this is in no small part to accidents such as the Chernobyl one. Other widely publicized accidents include the Three Mile Island and Tokaimura accidents. In March 1979 there was a partial meltdown of the core of the unit one reactor at Three Mile Island resulting in a significant release of radioactive gas. The industry claims there were no deaths or injuries from the accident. Their claim is supported by epidemiological studies (Hatch et al., 1990; Hatch et al., 1991) however Wing et al. (1997) found leukemia rates were 2 to 10 times higher downwind of Three Mile Island than upwind. The Tokaimura accident occurred when an experimental fast breeder reactor in the Japanese village of Tōkai reached criticality. There was no explosion since the self-sustaining fission reaction was occurring in a liquid environment. However, intense gamma and neutron radiation was released as the solution 'boiled vigorously' for 20 hours before the reaction abruptly ceased. Three operators received doses over permissible limits and two of these died. A report attributed the accident to 'human error and serious breaches of safety principles' (IAEA, 1999).

Climate change has provoked fierce and often polarized discussion. Lord Stern's famous report argued climate change would eventually cause melting glaciers, declining crop yields, temperature related deaths, rising sea levels displacing people and disruption to ecosystems. His report also argued climate change could be mitigated by technology change in the power sector which in 2006 contributed 24 per cent to $C0_2$ emissions (Stern et al., 2006). A major question concerns what role nuclear power might play in these technical changes. It is now 25 years since the Chernobyl accident and contemporary nuclear technology is safer now than in 1986 so nuclear power may be a possible part of the solution to increasing $C0_2$ levels. However, the spectre of Chernobyl still exists and, in much of the debate, the nuclear option is still very much the 'N word'.

2. Diseases and Deaths from the Chernobyl Accident

The most important losses from Chernobyl were human losses and WHO (2006) is the main source of information here, though other more recent sources are used where appropriate. WHO (2006) is a report by the World Health Organisation Report produced for the Chernobyl Forum, an inter-agency initiative of the United Nations launched in 2003 to achieve consensus over the impacts of the Chernobyl accident from a multi-disciplinary perspective[2].

Diseases caused by radiation from the accident

Over 6,000 cases of thyroid cancer[3] were found in children and adolescents (0 - 17 years) from Belarus, Ukraine and the most affected areas of Russia between 1986 and 2005 (UNSCEAR, 2008). The incidence rate of childhood thyroid carcinoma in Belarus reached 40 per million compared to one per million per year in other countries (Williams, 2009). The main cause was internal irradiation from iodine-131 resulting from consumption of fresh milk. Children, drinking milk, having smaller thyroid volume and more likely to be suffering from iodine deficiency, were the most vulnerable group (Cardis et al., 2005). Other factors such as age at exposure, iodine intake, endemic goitre, metabolic status, screening frequency for thyroid cancers in affected populations, short lived iodine isotopes other than iodine-131, higher doses than expected and, possibly, genetic predisposition may also have been influential (WHO, 2006).

The incidence of thyroid cancer in adults was quite different to that for children however still elevated. One such study was of 99,000 liquidators living in six regions of Russia that found only 58 cases of thyroid cancer (Ivanov et al. 2002). Another study of 101,000 liquidators who worked within the 30km zone between April 1986 and December 1987 found only 115 cases of thyroid cancer (Kesminiene et al. 2002). Adult radiation induced thyroid incidence was still observed two decades after the Chernobyl accident and is expected to remain elevated (WHO, 2006).

The standard treatment for thyroid cancer is total thyroidectomy and radioiodine treatment plus thyroid stimulating hormone and suppressive therapy. Rybakov et al. (2000) reports on treatment of 330 children in the Institute of Endocrinology in Kiev with half the patients from contaminated areas. Cancer recurrence was 2.8% and general mortality was 1.8%. This seems consistent with a range of studies reviewed in WHO (2006). More recently, Williams (2009) reviewed work on metastasis and lymph node spread and complications from treatments which turned out to be common but not usually fatal. He cites Demidchik et al. (2006) who, in a sample of 740 children, found that 6.2% suffered permanent recurrent laryngeal nerve damage and 12.3% suffered permanent hypoparathyroidism. Overall prognosis for young sufferers of thyroid disease was good. Of 1152 thyroid cancer patients diagnosed from Chernobyl children in Belarus during 1986-2005, 15 died due to progression of their cancer and six died from other causes, a survival rate of 98.8 per cent (UNSCEAR, 2008).

Incidence of leukemia has been shown to be increased by radiation exposure, with Marie Curie developing leukemia after working with radioactive isotopes. Leukemia has a latency period of three to five years. However, no statistically significant increased risk was found in the various groups from areas

[2] WHO (2006) builds on a number of reports including in particular the report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000).

[3] The susceptibility of the thyroid gland to internal irradiation and particularly iodine-131 is discussed in Shore (1992).

with measurable amounts of contamination from the Chernobyl accident. This included those *in utero* at exposure, potentially a high risk group (WHO, 2006).

'Solid cancers other than thyroid cancer' are often treated as a distinct group of cancers in these types of studies. In this context, leukemia and other blood and lymphatic cancers are often more likely to be caused by radiation than cancers of other organs, the so-called 'solid' cancers. There are methodological issues with examining susceptibility to this group of cancers caused by possible thresholds in response rates, controlling for age and gender and, most important, because the typical minimal latency period from previous high dose studies is 10-15 years (WHO, 2006). UNSCEAR (2000) found no evidence from published studies that solid cancers in workers in contaminated areas were at elevated rates. However, since such cancers would only have started to emerge in the late nineties that result would have been of limited value. WHO (2006) reviewed studies undertaken since 2000 by Ivanov et al. (2004a) and Ivanov et al. (2004b) using large Russian samples of liquidation workers and found solid cancer rates were the same as for the general Russian population. There is evidence from Ukrainian cancer registries that female Chernobyl liquidators and evacuees have elevated breast cancer rates however WHO (2006) found that study had methodological issues and more work was needed. Generally, the consensus appears to be that non-thyroid solid cancer rates amongst vulnerable groups have not been influenced by the Chernobyl accident. However, WHO (2006) argued caution was needed drawing conclusions given the long latency periods.

WHO (2006) also examined studies of non-cancer diseases especially cataracts, cardiovascular diseases, immunological systems effects and heritable effects and were cautious about drawing conclusions. Epidemiological and mortality studies are complicated by the breakup of the Soviet system in 1991 and its aftermath with widespread psychosocial and health effects. During that period life expectancy for Russian and Ukrainian males fell from 70 to 61 and 67 to 61 years respectively (WHO, 2006).

The most sensitive ocular tissue is the lens and irradiation from Hiroshima and Nagasaki was shown to cause cataracts (Otake & Schull, 1982). Empirical work focusing on liquidators who suffered acute radiation effects found evidence of cataracts (WHO, 2006) and Day, Gorin & Eller (1995) found a small (3.6%) but significant group of 5-17 year olds living around the plant and exposed to radiation with cataract damage.

Cardiovascular disease is also associated with high levels of radiation. In the context of Chernobyl, these diseases are mainly associated with acutely affected liquidators and radiation therapy, however lifestyle changes in vulnerable groups such as less physical activity, smoking and drinking are pertinent (WHO, 2006). In the same vein, UNSCEAR (2000) report higher rates of mental disorders and morbidity for populations living in contaminated areas, reflecting psycho-social trauma and compounding cardiovascular and other disorders. WHO (2006) argue that there are important gaps in the epidemiological studies in this area and ongoing monitoring of vulnerable groups is important.

WHO (2006) also examines evidence for a number of other health areas likely to be effected by radiation exposure. Immunological disorders were examined and no evidence of excess autoimmune disorders discovered. Male fertility remains controversial since fertility declined in contaminated areas however there is no evidence of a dose relationship. It seems likely people exposed to high doses would have been affected. The evidence is also inconclusive for birth rates, still births and delivery complications, birth defects and Down's Syndrome. Birth rates have fallen and birth defects and Down's Syndrome are higher in contaminated areas. However, falls in birth rates may reflect unwillingness to have children after 1986 because of fears of birth defects. WHO (2006) concludes there is no evidence relating these outcomes to dose and, generally, they reflect trends in control populations. Some of these results have been challenged. Recently Wertelecki (2010) obtained results with respect to birth defects conflicting with WHO (2006) however concedes[4] that difficulties with controls mean the results are not definitive.

Mental disorders from the Chernobyl accident are examined in WHO (2006) in the categories of (i) stress related disorder, (ii) brain development in children, (iii) organic brain disorders and (iv) suicide rates in liquidators. WHO (2006) found no evidence for radiation related disorders in categories (iii) and (iv) for vulnerable groups. There was evidence of (i), post traumatic stress disorders, which had consequences for health behavior and adherence to safety protocols (Havenaar et al., 1997; Loganovsky et al. , 2007)). Public health initiatives have included educational programs, nine Community Development Centers for Social and Cultural Organisation across Belarus, Ukraine and Russia and a mental health information centre in Belarus (WHO, 2006). Child development concerns, (ii), were of great concern to populations in contaminated areas and attracted a great deal of attention from scientists. The best known study in that field, WHO (1995), did not find exposed children had elevated rates of retardation compared to controls. This result was supported by Lichter et al. (2000) who also found no differences in neuropsychological test performances of children of evacuees and controls.

Mortality

WHO (2006) provides a wide ranging discussion on the issue of total deaths however shies away from precise estimates citing concerns with the methodology used to make forecasts in earlier work. In particular, WHO is unwilling to estimate deaths outside of the groups with Acute Radiation Syndrome (ARS) and known thyroid cancer deaths. They cite uncertainty about whether radiation doses were always measured properly and the inappropriateness of some of the risk coefficients for the conditions in which they were applied. There were also criticisms made by other researchers. Liquidators and other risk groups were examined more frequently than controls in the early 1990s when financial constraints reduced the number of autopsies conducted in the general population. Another possible source of bias was elevation of 'tumor expectancy' amongst doctors dealing with risk groups. For example, operations on children from contaminated areas with nodular thyroid lesions often occurred automatically because any nodules were seen as potentially malignant (Rahu, 2003; Jargin, 2009).

The number of 4000 total deaths appears repeatedly in the publications from the Chernobyl Forum after 2003 and is attributed to UNSCEAR (2000). However, this Committee backed down from this projection in its 2008 Report:

"Although the model based predictions have been published about possible increases in solid cancer incidence among the general population, for all the population groups considered the doses are relatively

[4] World Report, Lancet 24th April 2010.

small and are comparable to doses resulting from exposure to natural background radiation. The Committee has decided not to use models to project absolute numbers of effects in populations exposed to low doses because of unacceptable uncertainties in the predictions." (UNSCEAR, 2008)

So, how many deaths are attributable to radiation exposure from the Chernobyl accident? WHO (2006) provides two groups for consideration: (i) deaths from Acute Radiation Sydrome (ARS) in 1986 as well as deaths in 1987-2004 among ARS survivors, and (ii) fatalities that can be projected above spontaneous mortality levels among both liquidators and people living in contaminated areas in Belarus, Russia and Ukraine. ARS was originally diagnosed in 237 emergency workers with 134 confirmed after detailed clinical analysis. Among those 134, 28 died in 1986 due to ARS and a further 19 died between 1987 and 2004. Adding nine children who died from thyroid cancer should give a total of 56 certain deaths from radiation from the Chernobyl accident. This number, 56, has been widely used in reports and studies both in Australia and overseas however the true figures are still uncertain. For example, UNSEAR (2008) claims 15 children, not nine, died from progression of their thyroid cancer presumably reflecting more recent data since their report was produced three years later.

Given the latency issues involved with thyroid and other cancers and that most published studies have focused on Belarus, Ukraine and Russia and leave unanswered questions about other countries, the number of deaths from irradiation from Chernobyl will probably never be known.

Not knowing how many people died is frustrating since the size of this number, or at least its order of magnitude, is important for several reasons. First, it may be indicative of how dangerous (or safe) nuclear power is compared to alternatives. For example, in Burgherr et al. (2005) use mortality data from the ENSAD database to compare the safety of coal, natural gas, hydro and nuclear primary power generation, 40% of which is electricity. It turns out 0.876 people died per gigawatt year from coal, 0.093 from natural gas, 0.561 from hydro and 0.006 from nuclear between 1969 and 2000[5]. These results have been widely cited, see Gittus (2006), DPMC (2006), Fisher and Matysek (2008) and elsewhere.

Another reason accurate mortality and disease data is useful is that it facilitates allocation of funds between health, social and economic programs for people still affected by the accident. In fact, recent lowering of estimates of latency and predicted deaths by WHO and UNSEAR have led to more money for social programs for people relocated after the accident.

3. Environmental Losses

IAEA (2006), a discussion of the environmental impacts of the Chernobyl accident, was written as part of the Chernobyl Forum. It brought together results from many publications and the discussion that follows is largely a summary of that document unless otherwise indicated.

[5] The numbers for hydroelectricity exclude the 26,000 fatalities arising from the Banqiao/Shimantan dam accident in 1975.

Damage to the Urban Environment

The two towns most affected by fallout from the accident were Chernobyl, the town where the plant was located, and Pripyat, with a population of 50,000 and the closest city. Seventy one per cent of radiation fell in Ukraine, Belarus and Russia with other European countries, particularly to the northwest, affected. Many of these radionuclides had short half lives and have now decayed (IAEA, 2006) however long-lived radionuclides, such as plutonium, are still present in the Chernobyl Exclusion Zone (CEZ) 30km around the plant. There are still issues regarding the technical appropriateness of the storage facilities used for low level waste collected around the containment area.

Radionuclides fell on open areas such as lawns, parks, roads, squares, roofs and walls and evacuation of the population early in the accident reduced external radiation doses to the population. Cleanup in 1986 and later and rain substantially reduced contamination however created contamination in sewerage and sludge storage areas. In most of the settlements subjected to radioactive contamination the air dose rate above solid surfaces is at now pre-accident level however walls have not received the same weathering as roofs. Radiocaesium on asphalt surfaces caught up in street dust is less than 10% of initial deposits (IAEA, 2006; Andersson et al, 2002).

Damage to the Agricultural Environment

Radioactive fallout contaminated large areas in Ukraine, Belarus and Russia and also in the rest of Europe. In the early phase following the accident the main problem was plant contamination leading to contamination of animals that ate them. This was a major concern until iodine-131, contaminating milk and causing thyroid cancer in children, had decayed. That problem lasted about two months after which concerns focused on root uptake of radionuclides. Caesium-134 and Caesium-137 still cause agricultural losses in some Ukrainian, Belarus and Russian areas. Other radionuclides such as 241-Am and Plutonium did not cause a problem for agriculture however Strontium-90 was a problem near the reactor (IAEA, 2006).

After the early phase, contamination was influenced by soil type as well as the level of fallout. Soils with high organic or clay content and unimproved pasture had higher radioecological sensitivity and more likelihood of producing contaminated meat and milk, and to a lesser extent, vegetables. Small private farms competing with the large Soviet collectives and, in Northern and Western Europe, alpine meadows and upland regions with poor soils, were most affected (Kashparov et al., 2004).

The main agricultural counter measures after the early phase addressed animal contamination from grazing. Land used for fodder crops was treated, clean feeding was undertaken prior to slaughter and caesium binders were applied to animals. Some lands in both the three most affected countries and Western Europe were still out of use in 2006 (IAEA, 2006).

Damage to the Forest Environment

Tree canopies at forest edges are efficient filters of contaminants with 60-70 per cent of initial depositions being captured in the early phase. This led to many of the pine trees within a seven kilometer radius of the Chernobyl plant receiving lethal doses. Tree canopy contamination declined with natural leaf drop and radionuclides were transferred to the soil.

Some of the highest Caesium-137 concentrations were found in forest environments due to persistent recycling of radionuclides in forest ecosystems with Belarus, Russia, Ukraine, Finland, Sweden and Austria most affected. Human pathways are primarily food related, mushrooms, berries and game with additional concerns about burning and firewood collection (IAEA, 2006). The most prominent pathway affected appears to have been *lichen-reindeer meat-humans* in Arctic and sub-Arctic parts of Europe (IAEA, 2006).

Damage to the Aquatic Environment

Surface water systems were contaminated after the accident in areas close to the site and in many other parts of Europe. The majority of fallout was in the catchment of the Pripyat River a component of the Dneiper River reservoir system, an important water system in Europe.

Contamination decreased rapidly in the weeks after the accident through dilution, physical decay and absorption by catchment soils (Zibold et al., 2002). Significant concentrations of radionuclides were found in fish as far away as Scandinavia and Germany. The most contaminated lakes were 'closed lakes' in Belarus, Russia and Ukraine with limited inflows and outflows. Ocean fish were not significantly affected (IAEA, 2006).

Damage to the Wild Life Environment

Acute radiation effects occurred to wild animals and plants in the CEZ 30km around the plant with deaths, loss of reproduction, change of biodiversity and genetic anomalies. No acute radiation affects were reported beyond the CEZ. Changes were rapid in the first few years then the system settled down. At present, traces of adverse effects of the accident on biota around the plant can hardly be found and wild life is flourishing in the absence of humans (IAEA, 2006).

The Chernobyl Plant Site

The plant, which comprises four reactors, was not finally decommissioned until 2000. There are still 22,000 spent fuel assemblies stored at the plant and unit four, where the accident happened, still contains 150 tons of fuel from the destroyed reactor. Long term storage solutions have not yet been implemented and many of the storage facilities, because of the emergency, were established without proper design documentation, engineered barriers or hydrogeological investigations (Amosova, 2008).

4. Evacuation & Relocation

Between 1986 and 1990 around 118,000 people from Pripyat and other nearby settlements in the 30km CEZ and, between 1991 and 2000 a further 218,000 people, were re-settled from contaminated lands (UNDP, 2002, p.66). UNDP (2002) argues that resettlement was overly cautious and its scale reflected the authoritarian basis of decision making: 'Because of the political environment, the Soviet State, with its vast resources, was able to embark on resettling several hundred thousand people without serious challenge from the communities involved.’ This (possible) over zealousness combined with personal compensation levels paid to victims, discussed below, may have contributed to the major adverse legacy affect of Chernobyl. That is, low living standards of Chernobyl victims today.

After the breakdown of the Soviet system in 1991 there were 135,000, 52,400 and 163,000 resettled people living in Belarus, Russia and Ukraine respectively. Infrastructure for servicing these people was lacking from 1986 and building programs were initiated under both the Soviet regime and, after 1991, continued these by all three governments. In total between 1986 and 2000 130,300 flats and houses were built, 144,000 places created in schools and kindergartens, 38,000 new outpatient visits per day provided and 11,000 new hospital beds (UNDP, 2002). In addition, new investment was required in electricity, roads and water.

UNDP (2002, p.30) argues that Soviet practice was to compensate people for exposure to risk rather than actual injury. ‘Chernobyl victims’ were defined to include those who became invalids as a result of the accident, participated in the clean-up activities or who continued to live in contaminated areas or were evacuated or resettled or left affected areas of their own initiative. Belarus and Russian legislation provided more than 70, and Ukrainian more than 50, privileges and benefits for Chernobyl victims. In all three countries each family member is paid a monthly bonus for living on contaminated territory with the amount depending on circumstances. Eventually, seven million victims of the Chernobyl accident were identified and compensated.

IAEA (2006b) argues that opportunities to obtain high levels of compensation combined with economic and social uncertainties associated with the breakup of the Soviet Union in 1991 contributed to a type of ‘illness behavior’ arising from a culture of dependency. People suffered from anxiety, in particular linked to unemployment and a feeling they did not have adequate control over their lives. This manifests as reduced reproduction rates and abuse of tobacco, alcohol and other drugs. In addition, affected populations exhibit a widespread belief that exposed people are in some way condemned to a shorter life expectancy. This is despite the main causes of death in the Chernobyl affected region being the same as those nationwide.

A number of reports have identified a need to change the priorities in future recovery work. UNDP (2002) says: ‘A log jam has developed of expectations and assumptions that no longer reflect current realities. Breaking this log jam is the key to resolving the continuing problems that have followed from the Chernobyl accident.’ UNDP (2002) identifies a group of between 100,000 and 200,000 people who are caught in a downward spiral and need substantial material assistance to rebuild their lives. A policy approach is discussed in the Appendix.

5. The Chernobyl Nuclear Accident Today

The objective of this paper was to examine the aftermath of Chernobyl. However, it is not always easy to be unbiased and one learns about oneself trying to be so. Perhaps a younger, more decisive, person than me with more appetite for risk and more at stake in the future would see things differently. She might say, ‘Chernobyl was a long time ago and, anyway, more people have died in traffic pileups on the autobahn. Let's move on.' She might also say 'What matters are storing nuclear waste products, stopping proliferation and whether nuclear is climate friendly anyway.' If she liked economics, she might talk about the costs per kilowatt of nuclear and whether it is a financially viable alternative to coal[6]. However, Generation Y did not grow up with movies like *China Syndrome*[7] or *Silkwood*[8]. They also did not wake up in 1986 to media broadcasts about a meltdown of a nuclear reactor in the Ukraine and predictions of 20,000+ deaths and talk of environmental devastation across Europe. They have different perspectives. However, it is important to obtain an understanding of Chernobyl that transcends these types of generational and cultural gaps and takes into account how perceptions are influenced by the peculiarities of particular events.

Overweighting of unlikely yet extreme events

How people deal with uncertainty is at the heart of how people feel about nuclear power and about the Chernobyl accident in particular. Until the 1960's, scientific understanding of decision making under uncertainty was dominated by expected utility (EU) theory (Von Neumann & Morgenstern, 1947). EU theory posited that people added probability weighted future outcomes to get expected changes in wealth and how they dealt today with these aggregated wealth changes depended on the curvature of their utility functions. The theory is succinct and axiomatically based and remains popular even today with some applied researchers. However, from early days it attracted criticism with the popular Allais and Ellsberg Paradoxes providing plausible examples of behavior that was inconsistent with the theory. Research by Quiggin (1982) and Machina (1983) led to conjecture about non-linear weights in expected utility functions (later called value functions) which resolved some of these inconsistencies and, with other dissenting papers, led to a general rejection of EU theory[9]. Interestingly, Quiggin's two papers, Quiggin (1982) and Quiggin (1993) throw some light on contemporary attitudes towards Chernobyl. His work predicted, at least theoretically, that *individuals are likely to overweight unlikely, extreme events* such as the Chernobyl accident. Development of this work by Amos Tversky and Nobel Prize winner Daniel Kahneman[10] after 1992 led to the discovery and development of Cumulative Prospect Theory. That theory provided the conclusion about *overweighting of unlikely, extreme events* with more powerful theoretical foundations than before and could be empirically supported. This research has great explanatory power and explains things as diverse as why individuals who are normally loss avoiding buy lottery tickets or why they may be sanguine about road deaths while simultaneously worrying about earthquakes. Tversky and Kahneman's discoveries are of vital importance in our understanding of Chernobyl since they throw light on the importance placed on the accident even today and on contemporary fears about the commissioning of new reactors.

---

[6] Nuclear storage issues have a large literature with the IAEA's 'Nuclear Safety Review for the Year 2010' and other IAEA publications being good starting points for reading. Whether nuclear really is 'green' is discussed in Mortimer (1991), Lenzen (1999) and elsewhere; relative kilowatt costs of nuclear versus energy from other sources are discussed in Lenzen (2009), Matysek, A.L. and B.S. Fisher (2008), Gittus (2006) and elsewhere.

[7] The movie China Syndrome, a drama about a nuclear reactor melting down, released 12 days before the Two Mile Island accident, was a blockbuster hit and doubtless contributed to public perceptions of nuclear risks.

[8] *Silkwood* is about Karen Silkwood (1946-1974) a nuclear plant worker who died while investigating safety violations made by her employer.

[9] For a humorously written and insightful essay on the weaknesses in EU theory see Rabin and Thaler (2001).

[10] Tversky and Kahneman (1992) and other papers by these two authors.

In the context of climate change, it is disturbing that so many aspects of the Chernobyl accident conspire against people being objective in any scientific sense:

- As discussed above, individuals are likely to place too much importance on unlikely, extreme events such as the Chernobyl accident.
- The accident occurred during a period of deep public distrust of the nuclear power industry following the Three Mile Island incident, the afore mentioned movies and the distrust of government authority in Western countries from the Vietnam war era.
- Early reports of the accident in the press were wildly wrong in their estimates of deaths and environmental losses from the accident and resulted in a worldwide panic. The full truth about losses took decades to emerge and, buried in United Nations reports, never attracted great publicity.
- The huge amounts paid in compensation to so many Chernobyl victims in a time of social upheaval as the USSR broke down politically created a constituency that benefited from overstatement of losses from the accident.
- The emergence of climate change galvanized and enriched conservation groups who traditionally oppose nuclear development and who benefit from *status quo* beliefs about Chernobyl.

Three conclusions can be drawn from this study. First, the Chernobyl accident is still very important for the victims many of whom still need care and support. Second, nuclear reactors are potentially very destructive so the greatest care is needed in their design, construction, maintenance and operation. Third, losses arising from Chernobyl were not of sufficient magnitude and the event was so long ago that the accident should not be definitive in decisions about investment in new reactors.

In the context of climate change and the nuclear debate, future research should address:

- Will future accidents with reactors result in the same level of losses, or lower losses, than occurred at Chernobyl?
- Can nuclear waste products from uranium mines and reactors be stored with acceptable levels of risk?
- Can proliferation problems linked to nuclear electricity production be managed with acceptable levels of risk?

References

Andersson, K.G., Roed, J. and C.L. Fogh, 2002, Weathering of radiocaesium contamination on urban streets, walls and roofs, Journal of Environmental Radioactivity, 62, 49-60.

Anspaugh, L.R., 2008, 'Environmental consequences of the Chernobyl accident and their remediation: 20 years of experience', *Chernobyl: looking back to go forward,* Proceedings of the International Conference on Chernobyl organized by the International Atomic Energy Agency, Vienna.

Cardis, E., Kesminiene, A., I vanov, V., Malakhova, I., Shibata, Y., 2005, Risk of thyroid cancer after exposure to iodine-131 in childhood, Journal of National Cancer Institute, 97, 724-732.

Danzon, M., 2008, Opening Address, *Chernobyl: looking back to go forward*, Proceedings of the International Conference on Chernobyl organized by the International Atomic Energy Agency, Vienna.

Day, R., Gorin, M.B. and A.W. Eller, 1995, Prevalence of lens changes in Ukrainian children residing around Chernobyl, Health Physics, 68, 632-42.

Demidchik, Y.E., Demidchik, E.P., Reiners, C., Biko, J., Mine, M.,Saenko, V.A. et al., 2006, Comprehensive clinical assessment of 740 cases of surgically treated thyroid cancer in children of Belarus, Annals of Surgery, 243, 525-32.

DPMC, 2006, Uranium mining, processing and nuclear energy: opportunities for Australia, Department of the Prime Minister and Cabinet, Australian Government, Canberra, Australia, p.66.

ElBaradei, M., 2008, The enduring lessons of Chernobyl, *Chernobyl: looking back to go forward*, Proceedings of the International Conference on Chernobyl organized by the International Atomic Energy Agency, Vienna.

Gerasimova, N., 2008, Long Term consequences of the Chernobyl catastrophe and remediation programs in the Russian Federation' *Chernobyl: looking back to go forward,* Proceedings of the International Conference on Chernobyl organized by the International Atomic Energy Agency, Vienna.

Gittus, J.H., 2006, Introducing nuclear power to Australia: an economic comparison, Report prepared for the Australian Nuclear Science and Technology Organisation.

Hatch MC, Beyea J, Nieves JW and M. Susser, Cancer near the Three Mile Island nuclear plant: radiation emissions. Am J Epidemiol 132:397-412 (1990).

Hatch MC, Wallenstein S, Beyea J, Nieves JW and M. Susser, 1991, Cancer rates after the Three Mile Island nuclear accident and proximity of residence to the plant, *American Journal of Public Health* 81 (6): 719–724.

Havenarr, J.M., Rumyantzeva, G.M., Van Den Brink, W., Poelijoe, N.W., et al. ,1997, Long term mental health effects of the Chernobyl disaster: an epidemiological survey in two former Soviet regions, American Journal of Psychiatry, 154, 1605-7.

Burgherr, P., Hirschberg, S., Hunt, A. and R.A. Ortiz, 2005, Severe accidents in the energy sector, PSI Report prepared for the European Commission within Project NewExt on New Elements for the Assessment of External Costs from Energy Technologies, Paul Scherrer Institute, Wuerenlingen and Villigen, Switzerland.

IAEA, 1999, Report on the preliminary fact finding mission following the incident at the nuclear fuel processing facility in Tokaimura, Japan' Report of the International Atomic Energy Association, Vienna.

IAEA, 2006b, Chernobyl's legacy: health, environmental and socio-economic impacts and recommendations to the governments of Belarus, the Russian federation and Ukraine, International Atomic Energy Association, Austria, IAEA/PI/A.87 Rev.2/ 06-09181

Ivanov, V., Ilyin, L., Gorskia, A., Tukov, A. and R. N. Naumenko, 2004a, Radiation and epidemiological studies analysis for solid cancer incidence among nuclear workers who participated in recovery operations following the incident at the Chernobyl NPP, Journal of Radiation Research, 45, 41-4.

Ivanov, V.K., Gorski, A., Tsyb, A.F., Ivanov, S.I., Naumenko, R.N. and L.V. Ivanova, 2004b, Solid cancer incidence among nuclear workers residing in Russia: estimation of radiation risks, Radiation Environmental Physics, 43, 35-42.

Ivanov, V.K., Tsyb, A.F., Petrov, A.V., Maksioutov, M.A., Shilyaeva, T.P. and Kochergina, E.V., 2002, Thyroid cancer incidence among liquidators of the Chernobyl accident: absence of dependence of radiation risks and prognosis. Proceedings of the 4th Symposium on Chernobyl-related Health Effects, Tokyo.

Jargin, S.V., 2009, Overestimation of Chernobyl consequences: calculation of a latent period for tumors with unproven radiation etiology, Radiation Environmental Biophysics, 48, 433-4.

Kashparov, V.A., 2004, Kinetics of dissolution of Chernobyl fuel particles in soil in natural condition, Journal of Environmental Radioactivity, 72, 335-353.

Kesminiene, A., Cardis, E., Tenet, V. Ivanov, V.K., Kurtinaitis,J., Malakhova,I., Stengrevics, A. and M. Tekkel, 2002, Studies of cancer risk among Chernobyl liquidators: materials and methods, Journal of Radiological Prot. 22, 137-41.

Lenzen, M., 2009, Current state of development of electricity-generating technologies: a literature review. Report from Integrated Sustainability Analysis (University of Sydney) for the Australian Uranium Association.

Lenzen, M., 1999, Life cycle energy and green house gas emissions of nuclear energy: a review, Energy Conversion & Management, 49, 2178-2199.

Litcher, L., Bromet, E.J., Carlson, G., Squires, N., Goldberg, D., Panina, N., Golovakha, E. and S. Gluzman, 2000, School and neuropsychological performance of evacuated children in Kyiv 11 years after the Chernobyl disaster, Journal of Child Psychol Psychiatry 41, 291-9.

Loganovsky, K., Havenaar, J.M., Tintle, N.L., Guey, L.T., Kotov, R. and E.J. Bromet, 2007, The mental health of clean up works 18 years after the Chernobyl accident, Psychological Medicine 38, 481-8.

Machina, M., 1982, Expected utility analysis without the independence axiom, Econometrica 50, 277-323.

Matysek, A.L. and B.S. Fisher, 2008, Prospects for nuclear power in Australia and New Zealand, Journal of Global Energy Issues, 30, 309-323.

Mortimer, N., (1991) Nuclear power and global warming', Energy Policy 19, 76-78.

Otake, M., and W.J. Schull, 1982, The relationship of gamma and neutron radiation to posterior lenticular opacities among atomic bomb survivors in Hiroshima and Nagasaki, Radiation Research, 92, 574-595.

Quiggin, J., 1982, A theory of anticipated utility, Journal of Economic Behavior & Organization 3, 323-343.

Quiggin, J., 1993, Generalized Expected Utility Theory. The Rank-Dependent Model, Boston: Kluwer Academic Publishers.

Rabin, M. and R. H. Thaler, 2001, Anomalies: risk aversion, Journal of Economic Perspectives 15, 219-232.

Rahu, M., 2003, Health effects of the Chernobyl accident: fears, rumors and the truth', European Journal of Cancer, 39, 295-299.

Rybakov, S.J.,Komissarenko, I.V., Tronko, N.D., Kvachenyuk, A.N., Bogdanova, T.I., Kovalenko, A.E. and M.Y. Bolgov, 2000, Thyroid cancer in the children of Ukraine after the Chernobyl accident, World Journal of Surgery 24, 1446-9.

Shore, R.E., 1992, Issues and epidemiological evidence regarding radiation-induced thyroid cancer, Radiation Research, 131, 98-111.

Stern, N., S. Peters, V. Bakhshi, A. Bowen, C. Cameron, S. Catovsky, D. Crane, S. Cruickshank, S. Dietz, N. Edmonson, S.-L. Garbett, L. Hamid, G. Hoffman, D. Ingram, B. Jones, N. Patmore, H. Radcliffe, R. Sathiyarajah, M. Stock, C. Taylor, T. Vernon, H. Wanjie, and D. Zenghelis (2006), Stern Review: The Economics of Climate Change, HM Treasury, London.

Tversky, A. and D. Kahneman, 1992, Advances in prospect theory: cumulative representation of uncertainty, Journal of Risk and Uncertainty 5, 297–323.

UNDP, 2002, The human consequences of the Chernobyl nuclear accident: a strategy for recovery, Report to the UNDP and UNICEF with the support of UN-OCHA and WHO, February.

UNSCEAR, 2000, United Nations Scientific Committee on the Effects of Atomic Radiation 2000 Report to the General Assembly, with Scientific Annexes. Volume II: New York, United Nations.

UNSCEAR, 2008, Report of the United Nations Scientific Committee on the effects of atomic radiation, 56th session of the General Assembly, 10-18 July.

Wertelecki, W., 2010, Malformations in a Chernobyl impacted region, Pediatrics 125 4, 836-843.

WHO, 1995, World Health Organization report of the international project for the health effects of the Chernobyl accident, Geneva.

WHO, 2006, World Health Organisation report on Health Effects of the Chernobyl Accident and Special Health Care Programs, Report of the UN Chernobyl Forum Expert Group, “Health”, Bennett, B., Repacholi, M., and Z. Carr (eds).

Williams, D., 2009, Radiation carcinogenesis: lessons from Chernobyl, Oncogene 27, S9-S18.

Wing S, Richardson D, Armstrong D, Crawford-Brown D., (1997) A reevaluation of cancer incidence near the Three Mile Island nuclear plant: the collision of evidence and assumptions, Environ Health Perspect 105:52-57.

Zibold, G., Kaminski, A.V., Klemt, E. and J.T. Smith, 2002, Time dependency of caesium-137 activity concentration in fresh water lakes, measurement and prediction, Radioprotection Colloques 37, 75-80.

APPENDIX

YOUTH PROJECTS IN ZAMGLA Y VILLAGE IN THE RIPKYNSKY DISTRICT OF THE CHERNIHIV REGION[11]

N.NASON

Youth Community Leader, Zamglay Village, Ukraine

The population of Zamglay village is 1985 and about 400 inhabitants are young people. The village is located 70 km from the Chernobyl nuclear power plant and experienced radioactive contamination during the disaster.

As the years passed, radiation conditions fortunately improved, but unemployment and poverty caused by the closure of local enterprises became much worse. Impoverishment of the population has caused alcoholism and drug addiction of young people. Apathy and passivity towards life developed in people. People became accustomed to receiving low subsidies from the State authorized to "chernobyltsy" (Chernobyl-affected people) and to doing nothing, dragging out a passive existence.

People who were looking for a better life began to leave the village. The situation was difficult. People finally understood that they should not rely on the help of others. People said: "If we don't help ourselves, who will help us? We can help ourselves!" was the answer. We have understood that our power lies in our unity.

In March 2003, the population of the village united in two organizations: 'Pobeda' (Victory) organization and 'Ogonyok' (Light) community organization. We have jointly defined priorities and common projects for village recovery. We started by putting the cemetery in order, cleaning the streets, repairing the fences, water supply systems, wells and reconstruction of the local market.

We then implemented projects on reconstruction of health clinics, repairing the school's workshop and sports ground, and laying a gas supply system. We implemented these projects with the assistance of the UNDP's Chernobyl Recovery and Development Programme.

Young people from the village had their own problems and priorities. First of all, there were problems with organized leisure time, with sports, education, computer literacy and business for beginners, communication with people of the same age in the district, Ukraine and in the whole world.

To solve these problems, the youth of Zamglay village, seeing the results of the adults' work, established its own 'TEMP' youth organization. The acronym TEMP translates as 'tempo' and stands for Talented Erudite Young Generation. TEMP is a movement towards achieving a goal. Practically all of the active youth of our village have joined this community organization.

The project that was implemented with the assistance of the UNDP is Youth Service Centre Establishment. This initiative was supported by several local authorities, and above all by the village

[11] Extract from the papers of the Chernobyl Forum

council. Due to the joint efforts of our organization and local authorities we managed to mobilize the resources needed to implement the project.

At present, the centre is a reality. We have premises repaired by ourselves; we have sport and computer equipment. We have received literature on the consequences of the Chernobyl catastrophe. There are classes for people with different interests. There is a computer class, a local newspaper is published, and trainings and seminars are held.

Most importantly, the youth now comes together to pursue their interests, drawing them away from harmful pursuits. Due to the existence of the youth centre, the youth has stopped leaving the village. The youth has become more active and purposeful, because they saw real results from their work. They have become more independent and self-sufficient. The local government now elaborates new projects, and looks for sponsors and donors.

We plan to develop the youth centre into a resource centre at the district level. Young people from our district and also from other Chernobyl-affected regions of the country come to the centre to adopt its methods. One of the main factors for achieving success is education. Especially needed is knowledge in business development, economic recovery of the village as well as skills in using computers and internet technologies.

The youth centre is known for improving access to information. By participating in trainings organized by the UNDP and other organizations, and having received knowledge ourselves, we do everything possible to share our knowledge with our younger friends and people of the same age from other villages. To this end, we have elaborated and implemented a training plan. The goal is for the youth centre to continue its development in the hands of a new generation.

Last year, young people actively participated in the Rayon Economic Forum on economic recovery and development of villages. Together with representatives from the district administration, heads of villages, representatives of communities and business, they discussed the economic problems of the region and developed ways to solve them. Young people are already working on elaborating small business projects. If there is a possibility to work and to earn money, the youth will not rely on State subsidies. Of course, it is understood that it will not be easy to realize our plans.

There are also problems. The absence of telecommunications infrastructure does not allow reliable modern access to the internet. To implement business plans, available credit lines, training and experience are needed. This requires the assistance of the international community and the State. However, we have already learned the most important lesson - the most important source of recovery and renewal comes from relying on ourselves.