Recent Fukushima nuclear detonation, Chernobyl nuclear fallout, three mile island nuclear accident and atomic bomb explosion – rethinking the effects of nuclear radiations over human health

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▶ ***Review article***

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ABSTRACT

Background: The earlier Atomic Bomb explosion in Hiroshima and Nagasaki, and three worth mentioning nuclear accidents - detonation at Fukushima Daiichi nuclear plant, Chernobyl nuclear fallout and an accident at Three Mile Island nuclear power plant have made us more worried about the secure exploitation of nuclear energy. The central focus of this paper is to review radiation-mediated health effects on human beings based on past and present incidences of nuclear detonations and/or accidents. ***Materials and Methods:*** The Data used in this review were mainly from PubMed and Medline in English, and recent data were taken from different types of renowned international organizations and newspapers. The study selection involves articles related to Fukushima nuclear detonation and radiation risks, health hazards due to radiation from Chernobyl nuclear fallout, Three Mile Island nuclear accident and radiation impacts and Atomic Bomb explosion and radiation-related health effects were selected. ***Results:*** The epidemiological studies based on past and present incidences of nuclear detonations and/or accidents entail both radiations mediated immediate and protracted effects and/or risks over human health. The individuals affected by radiation exposure, survivors of nuclear radiations and their subsequent generations are arrested by varying sorts of cancers and non-cancer diseases along with psychological implications and genetic disorders. Among the worst sufferers are pregnant women, fetus and children; though it affects all ages and sexes of people. ***Conclusion:*** Since the safely and peaceful usage of nuclear energy is in question, today's global health is at risk and none of us free from it.

Keywords: *Cancers, genetic disorders, non-cancer diseases, nuclear accidents, psychological impacts, radiation effects.*

INTRODUCTION

The 11 March 2011 detonation at Fukushima Daiichi nuclear plant [1, 2, 3], Chernobyl nuclear fallout on 26 April 1986 [4], an accident at Three Mile Island nuclear power plant on 28 March 1979 [5] and on August 6 and August 9, 1945, atomic bomb explosion in Hiroshima and Nagasaki [6] respectively – all these events have been threatening the peaceful and safely exploitation of nuclear energy to meet the world's energy crises. The recent accident at Fukushima nuclear plant has made us more worried about the safety of nuclear power and opened the chapter of many debates and controversies about the usage and utilization of nuclear energy. Any kind of nuclear explosions from either nuclear weapons or nuclear power plants emit a large amount of intense heat, physical forces and ionizing radiations having immense immediate and long terms adverse effects on human beings and environment. The immediate impacts include deaths, burns, infections, trauma and other physical injuries and protracted effects reflect cancers and non-cancer diseases, and environmental hazardous effects include air, water and soil, and food contaminations. Besides the devastating and destructive forces of nuclear detonation, it discharges more dangerous and hazardous radiations characterized by prolonged effects on human health and surroundings that have given it a unique form of distinctness from all other types of explosions. To speak more specifically ionizing radiations released by nuclides affect not only human but also any kind of living objects ranging from unicellular to multicellular ones or in broad sense from prokaryotes to eukaryotes. The paper mainly reflects radiation-mediated health effects and/or probable risks on human owing to nuclear detonations.

Fukushima nuclear detonation and possible radiation risks

The great and deadly devastation in Japan on 11th March, 2011, caused by magnitude-9.0 earthquake and subsequent tsunami left 28,000 people dead or missing accompanied by another calamity at Fukushima nuclear power plant [1-3, 7, 8]. The estimated financial cost stands at $300 billion making it the world's most expensive disaster [9].

The ongoing leakages of radioactive materials from the crippled Fukushima Daiichi nuclear power plant have raised concern that some workers and even the public could be exposed to dangerous levels of radiation [10]. The nuclear blast has emitted nuclides specially radioactive ^{131}I (half-life of 8 days) and ^{137}Cs (half-life of 30 years) – total amount of radioactive discharges into air in accordance to Nuclear and Industrial Safety Agency (NISA) and Japan Nuclear Energy Safety Organization (JNES) has reached 3.7×10^{17}Bq and 6.3×10^{17}Bq respectively, and as per Tokyo Electric Power Co. the estimates were 7.2×10^{20}Bq and 1.5×10^{20}Bq on March 11 (date of the disaster) and April 11(after one month) respectively [11, 12]. Japan has raised the severity of its nuclear crisis to a level 7, the highest level (means a major accident indicating releases of radioactive materials with widespread health and environmental effects that requires implementation of planned and extended countermeasures) and radiations released are considered as 10 percent of Chernobyl [9, 13]. The residents within the 20km radius from the Fukushima damaged plant have been evacuated [14]. Radiation measured (samples collected 330 meters south of the outlets of no.1-no.4 reactors at 13:55 March 30) in the waters and air near the No.1 Fukushima Nuclear Power Plant was 180 Bq/cc ^{131}I (4385.0 times the acceptable value), 47 Bq/cc ^{134}Cs (783.7 times the acceptable value) and 47 Bq/cc ^{137}Cs (527.4 times the acceptable value) [14]. The dumping of more than 11,000 tons of radioactive water from the Fukushima Daiichi nuclear plant into the Pacific Ocean have raised global concern and criticism and elements like cesium 137 has been found in fish [15, 19]. Even before the dumping, radiation in the water near plant greatly exceeded legal limits estimating iodine 131 at five million times the acceptable level at one location due to leakage of nuclear plant [16]. EPA (US Environmental Protection Agency) has detected trace amounts of radioactive materials in air, drinking water, precipitation & milk in USA which were far below levels of public health-health concern following Japanese nuclear incident proved that radiation had reached the farther parts of the world [17, 18]. The screening performed to 91,768 people from March 13th to March 25th by Fukushima Prefecture has shown that 98 people were above the 100,000cpm. On March 24th, examinations of thyroid gland for 66 children aged from 1 to 15 years old were carried out but no ill effects have been found [14]. Among nuclear workers at Fukushima plant, 19 ones are exposed more than 100mSv, out of them three workers are exposed to more than 170mSv. Two workers out of three ones have been reported by National Institute of Radiological Sciences to be exposed at 2-6Sv (specially their legs). Some of them have been affected by minor radiation sickness [14, 15]. On 16 March Japan's ministry of science measured radiation levels of up to 0.33 mSv/h 20 kilometers northwest of the power plant [166]. In April, 2011, the United States Department of Energy published projections of the radiation risks over the next year (that is, for the future) for people living in the neighborhood of the plant. Potential exposure could exceed 20 mSv/year (2 rems/year) in some areas up to 50 kilometers from the plant and it is a level that could cause roughly one extra cancer case in 500 young adults (168). As of August 2011, the crippled Fukushima nuclear plant is still leaking low levels of radiation and areas surrounding it could remain uninhabitable for decades due to high radiation. It could take "more than 20 years before residents could safely return to areas with current radiation readings of 200 millisieverts per year, and a decade for areas at 100 millisieverts per year" [170]. All citizens of the city of Fukushima have received radiations and it have been concluded that they were exposed to not more than 0.3 mSv in September 2011 [167]. The normal background radiation varies from place to place but delivers a dose equivalent in the vicinity of 2.4 mSv/year, or about 0.3 µSv/h [169].

On 9 October, 2011 a survey done by the Medical University of Fukushima in response to concerned parents, alarmed by the evidence showing increased incidence of thyroid cancer among children after the 1986 Chernobyl disaster, started in the prefecture Fukushima: ultrasonic examinations were done of the thyroid glands of all 360.000 children between 0 to 18 years of age. Follow-up tests will be done for the rest of their lives. At the end of 2014 the initial testing of all children should be completed, after this the children will undergo a thyroid checkup every 2 years until they turn 20, and once every 5 years above that age [171, 172].

Approximately 100,000 people, in evacuation zones extending up to forty kilometers (equivalent to twenty-five miles) from the reactor site, were evacuated or otherwise "displaced"; when and if, they can return to their homes is unclear. The Japanese government has delineated a "contamination zone" of 930 square miles that will be targeted for comprehensive cleanup; such an operation will not be trivial. Based on measurements of ^{137}Cs in soil samples, one study has estimated that the region northwest of the plant has been contaminated with 1,000 kilobecquerels (KBq) per square meter. By way of comparison, in the aftermath of the Chernobyl accident, Soviet authorities permanently evacuated areas with approximately 1,500 kBq per square meter. Because the half-life of ^{137}Cs is thirty years, soil contamination and associated remediation efforts (such as the removal of topsoil from affected cropland) will have long-term impacts on the future of agriculture and food production in many areas of Japan which will affect human health too [177, 178].

Health hazards due to radiation from chernobyl nuclear

The 26 April 1986 accident at the Chernobyl nuclear power plant contaminated not only Ukraine, Belarus and the Russian Federation but also Austria, Bulgaria, Finland, Norway and Sweden and dispersed mainly a vast amount of ^{131}I and 137Cs into atmosphere as well as into the troposphere and stratosphere of the Northern Hemisphere up to at least 15 km altitude [4, 21-23]. People living in the most contaminated areas of the former Soviet Union received an average annual whole body radiation doses in 1986 – 1995 of 0.9 mSv in Belarus, 0.76 mSv in Russia, and 1.4 mSv in Ukraine and during next 70 years the global population will be exposed to a total Chernobyl dose of approximately 0.14 mSv, or 0.08% of the natural lifetime dose of 170 mSv.21 The average doses estimated for the period 1986 – 2005 was 2.4 mSv in Belarus, 1.1 mSv in Russia, and 1.2 mSv in Ukraine [24] WHO has estimated that the total radioactivity from Chernobyl was 200 times that of the combined releases from the atomic bombs dropped on Hiroshima and Nagasaki.

In the Rivne province of Ukraine, about 200 km from the Chernobyl plant, the rate of birth defects was far above the European average and it was estimated that 22 of 10,000 babies were born with a neural tube defect compared with the European average of nine per 10,000 babies [25]. The rate was even higher in the Polissia region classified as being 'significantly affected' by the disaster, with 27 of 10,000 babies born with a neural tube defect [25]. Polissia also had high rates of microcephaly and microphthalmia than in other parts of Rivne. Disaster related health problems have been found in 2·4 million Ukrainians including more than 400,000 children [25]. Exposure to 131I is associated with increased risk of thyroid cancers in childhood and is three times higher in iodine-deficient areas than elsewhere. After the Chernobyl accident, a large increase in the incidences of childhood and adolescent thyroid cancers (including follicular adenomas in some cases) were reported in radiation contaminated areas (specially in Ukraine, Belarus and the Russian Federation, and some other areas) [26-33, 39, 47]. The highest risk for thyroid cancer among those exposed to radioactive iodine was for the youngest age group (0–5 years) and there was also found an increased risk of thyroid cancer in children in utero exposure to radioiodines [31, 40, 41]. There was also recorded an enhanced risk of adult thyroid cancers [48]. Chernobyl-related thyroid carcinomas suggested that the solid morphology, aggressiveness and high frequency of RET-PTC3 rearrangements were features of radiation-induced tumors [71-73]. Besides thyroid carcinoma, radiation exposure from the Chernobyl accident was considered for an increased incidence of other thyroid diseases, particularly autoimmune thyroid disease (AITD) [34]. A significant increase of serum antithyroperoxidase antibody (TPOAb) prevalence was reported in a cohort of Belarusian (13 –15 yr after the Chernobyl accident) and Russian children and adolescents exposed to Chernobyl fallout [35-38]. Psychological effects were of considerable importance arising from an understandable fear of exposure to an unknown amount of an intangible but potentially dangerous agents, fear for exposed children, mistrust of reassurances from the authorities, and for hundreds of thousands of people, the consequences of forced evacuation from home and land and radiation sickness [42, 43]. Another consequence among genetic ones, not as firmly established as thyroid cancer, is mini-satellite instability (MSI) in children born to exposed fathers after Chernobyl accident [44-46]. An increase in spontaneous abortions was reported not only in the Chernobyl adjacent areas but also in Finland and Norway [49-53]. In Germany, perinatal mortality and trisomy 21 increased [54, 55]. A slight excess of Down syndrome and childhood leukemia were reported in Sweden among those who were in utero at the time of the accident [56]. Radiation has also negative effects on sex ratio explained by significantly decrease in male birth ratio than that of female one in the Czech Republic in November 1986 following Chernobyl plant blast which might result either from a change in the primarily determined sex ratio during conception or from a decrease in survival of males during the prenatal period [57, 58]. Radioiodine is the most probable cause of male fetus/neonatal death [58-60]. Prolonged exposure to low-dose radioactive 137Cs (found in Chernobyl) during childhood development reduces lung function and increases airway reactivity (obstruction and restriction) [61]. Modulation of the immune system leading to recurrent infections (as pulmonary infection) as a result of long-term exposure to radioisotopes dispersed from Chernobyl was recorded [62]. Hair loss, sterility, bone marrow destruction, internal bleeding or immune system failure that rapidly gives way to lethal infection were known due to Chernobyl radiation [63]. Data related to Chernobyl explosion showed a statistically significant reduction in red and white blood cell counts, platelet counts and hemoglobin in children with increasing residential ^{137}Cs soil contamination [64]. More transitory, prehemolytic and degenerative forms of erythrocytes (red blood cells) were found in exposed children in radioactive contaminated sites [65]. Human populations exposed to radiation from the Chernobyl nuclear power plant had elevated frequencies of abnormalities as well as birth defects [66-70]. Adolescents, who were exposed from the second trimester in pregnancy onwards, had an enhanced prevalence of lifetime depression symptoms such as ADHD (Attention

Deficit Hyperactivity Disorder) symptoms [74]. For all of the countries of Europe except Belarus, the first year average committed effective doses were below 1 mSv, ranging from 0.02 mSv for the whole of the UK through 0.07 mSv for the whole of Germany, 0.2 mSv for Greece up to 2 mSv for Belarus [81]. Nevertheless there were reported increases in infant leukemia in the in utero exposed cohort in Scotland, Belarus, Greece, Germany and Wales and Scotland combined and leukemia is believed to be a consequence of a gene mutation in utero [75-80]. Moreover, studies on the Chernobyl liquidators have reported increases in the incidences of leukemia among liquidators in Russia, Belarus and Ukraine [153-160].

Three Mile Island nuclear accident and radiation impacts

On 28 March 1979, an accident at Three Mile Island (TMI) nuclear power plant in Pennsylvania produced the release of small quantities of xenon and iodine radioisotopes into the environment. It was determined that the average likely and maximum whole-body Gamma-doses for individuals in this area were 9 mrem (0.09 mSv) and 25 mrem (0.25 mSv), respectively. The radiation from the TMI nuclear accident was considered minimal as compared to the approximately 300 mrem (3 mSv) annual effective dose received by an individual in the United States from natural background [5, 82].

Large percent increases in post-accident cancer rates per relative accident dose was recorded (all cancer = 2%, lung cancer = 8.2%, and leukemia = 11.6%) [83]. Another study found no definite effects of exposure on the cancer types and population subgroups considered but elevated risks for non-Hodgkin's lymphoma relative to accident emissions as well as for lung cancer [84]. But Wing *et al.* [83] analyzed data from the area nearest the TMI nuclear installation showing elevated cancer incidence rates and refuted earlier assumptions that low level radioactive emissions from the accident were too minute to produce observable effects [84]. There was a significant linear trend for female breast cancer risk in relation to increasing levels of TMI-related likely gamma exposure was also noted [85]. There also reports of erythema, hair loss, vomiting, and pet death near TMI at the time of the accident and of excess cancer deaths during 1979-1984 [86, 87]. Among psychological implications following TMI accidents were depression, distress, distrust and demoralization [88]. TMI had also showed persistent distress and even clinical levels of anxiety, depression and hostility, particularly in those living close to the plant [89-92]. A year after the accident, a sample of community residents exhibited significantly higher levels of stress hormones and stress symptoms than residents near undamaged nuclear or coal-powered plants [93]. A similar survey five years post-accident found evidence of chronic stress [94]. It was found that the group of pregnant women and mothers of small children was the most highly stressed of all groups tested [95, 96]. Stress had previously been cited as an etiological factor in the occurrence of spontaneous abortion [97]. Thirty-five percent of the five mile area residents polled one and a half years after the accident stated that they believed the number of miscarriages and stillborns had increased since the accident [95].

Atomic bomb explosion and radiation-related health effects

On August 6 and August 9, 1945, the Japanese cities of Hiroshima and Nagasaki, respectively, experienced the first and second use of atomic weapons in war introducing to the world a new class of weapons of mass destruction [6]. In Hiroshima, an estimated 90,000 to 166,000 deaths occurred within two to four months of the bombing in a total population of 340,000 to 350,000 and in Nagasaki, some 60,000 to 80,000 died in a population of 250,000 to 270,000 [6, 98, 99].

Radiation related health effects have been extensively studied in atomic bomb survivors. The long-term effects of A-bomb radiation on the T-cell system were observed in A-bomb survivors contributing to enhanced T-cell immunosenescence and resulted in significant increases of inflammatory responses which are involved in development of aging-associated and inflammation-related diseases such as increased risks of cardiovascular disease and other non-cancer diseases frequently observed in A-bomb survivors [100-102]. In persons receiving heavy doses of A-bomb radiation, both mature lymphocytes and bone marrow stem cells were severely damaged causing profound depletion of granulocytes and natural killer cells (for which exposed persons become vulnerable to active infections as common pathogenic *bacterium S. aureus*), innate immunity damaged (occurred only during the early period following the bombings), memory T cells affected exclusively (leading to reduced ability of the thymus to produce new T cells), numbers of CD4 T-cells (CD4+CD45RA+ naive T-cell subset) lowered (associated with myocardial infarction) and various inflammatory proteins increased, thus affecting the primary processes responsible for T-cell homeostasis and the balance between cell renewal and survival and cell death among naive and memory T cells [101-108]. Among A-bomb survivors, cataracts were seen within 3 to 4 years after the bombings necessitating lens surgery at doses under 1 Gy (0 to 0.8 Gy) and subsequent publications identified posterior subcapsular opacities as the ocular lesion that was most characteristic of radiation exposure [109-114]. Radiation exposed survivors were reported to have increased hypertension, higher cholesterol levels (greater for women than for men), fatty liver, low HDL (high density lipoprotein)-cholesterol, hypertriglyceridemia, aortic arch calcification, ischemic heart diseases, chronic liver diseases (fatty liver, alcoholic liver disease, and chronic hepatitis), uterine myoma and reduced hemoglobin levels, and it was estimated that deaths from heart disease and stroke make up more than half (54%) of noncancer disease deaths [115-122]. Findings showed that growth retardation had been a general result of childhood exposure to bomb radiation and larger doses (≥1 Gy) did cause decreased adult height by about 6 cm (or about 2.5 cm per Gy) [123, 124]. An increase in frank mental retardation (accompanied by reduced head size and an inappropriate migration of neurons to the ectopic gray matter of the cerebrum or faulty brain architecture) was found among those exposed in utero at 16 to 25 weeks and especially at 8 to 15 weeks postconception and showed a general decrease in IQ [125-127]. A survey conducted 17 to 20 years after the bombings reported higher frequencies of anxiety and somatization symptoms than those who were not in the city [128]. Chromosome aberrations were noticed among radiation exposed survivors of A-bomb explosion in Japan [129]. Incidences of solid cancers (excess relative risk value (ERR) 47%-48% following exposure to 1 Gy) including oral cavity, esophagus, stomach, colon, prostate, liver, renal, pancreas, lung, nonmelanocytic skin, female breast, ovary, uterus, urinary bladder, brain/central nervous system, salivary gland, parathyroid and thyroid tumors/cancers were noticed among the A-bomb exposed group (≥0.005 Gy), and reported higher risks of solid cancer incidences are associated with younger age at exposure and females have somewhat higher risks of cancer than males do [130-132,148-151]. The Life Span Study cohort of atomic bomb survivors showed higher risks of leukemia (acute lymphocytic leukemia, acute myelogenous leukemia, chronic myelocytic leukemia and adult T-cell leukemia) in the survivors (bone marrow dose of at least 0.005 Gy up to maximal 2 Gy) and even there is still evidence of a small increase in leukemia risk among the current survivors, and excess leukemia deaths were reported from radiation among those exposed as children [133-139]. In the Life Span Study and Adult Health Study cohorts, it was shown that a positive radiation dose-response relationship existed in thyroid cancer and thyroid nodules, and the incidence and prevalence of thyroid cancer increase with radiation exposure (women reported as having greater risk of thyroid diseases than men) [33, 140-145]. Skin cancers identified among survivors that included basal cell epithelioma, squamous cell carcinoma, basosquamous cell carcinoma, malignant melanoma, Paget's disease, tumors of epidermal appendages (such as sweat gland carcinoma) and dermatofibrosarcoma [146]. Statistics showed relationship between incidence of meningiomas and radiation exposure at atomic bombings [147].

Study on 86,572 people reported 9,335 deaths from solid cancer and 31,881 deaths from noncancer diseases during the 47-year follow-up. It was estimated that about 440 (5%) of the solid cancer deaths and 250 (0.8%) of the noncancer deaths were associated with the radiation exposure. The excess solid cancer risks appear to be linear in dose even for doses in the 0 to 150-mSv range [132]. It was documented that median life expectancy decreased with increasing doses at a rate of about 1.3 years/Gy, but declined more rapidly at high doses and estimated that at 1 Gy, the proportion of total life lost was roughly 60% from solid cancer, 30% from diseases other than cancer, and 10% from leukemia [152].

DISCUSSION AND CONCLUDING REMARKS

The epidemiological studies about effects of nuclear radiations over human health due to nuclear detonations or accidents suggest both long and short terms health effects and/or risks, which include canceral and non-canceral diseases along with psychological impacts and genetic disorders.

The radiation-induced cancers include thyroid cancers, lung cancer, non-Hodgkin's lymphoma, female breast cancer; tumors/ cancers related to oral cavity, esophagus and stomach; colon cancer, prostate cancer, liver cancer, renal cancer, pancreas cancer, lung cancer, ovary cancer, uterus cancer, urinary bladder cancer, cancers to brain/central nervous system; cancers to salivary gland, parathyroid and thyroid; higher risks of leukemia (acute lymphocytic leukemia, acute myelogenous leukemia, chronic myelocytic leukemia and adult T-cell leukemia), Skin cancers (basal cell epithelioma, squamous cell carcinoma, basosquamous cell carcinoma, malignant melanoma, Paget's disease, tumors of epidermal appendages and dermatofibrosarcoma) and Meningiomas.

The genetic disorders and psychological impacts include Perinatal mortality, trisomy 21, Down syndrome, sterility, leukemia due to consequence of a gene mutation in utero exposure, thus, related to chromosome aberrations and gene mutations; and aggressiveness, fear of radiation exposure and for exposed children, mental stresses due to consequences of forced evacuation, radiation sickness, ADHD (Attention Deficit Hyperactivity Disorder); distress, distrust and demoralization, depression and hostility, higher levels of stress hormones and stress symptoms, mental retardation, anxiety and somatization symptoms respectively.

The non-cancer diseases involve autoimmune thyroid disease, reduction of lung function and rise of airway reactivity, pulmonary infection, bone marrow destruction, immune system failure, erythema, development of aging-associated and inflammation-related diseases (cardiovascular disease), damage to both mature lymphocytes and bone marrow stem cells, depletion of granulocytes and natural killer cells, innate immunity damaged, memory T-cells affected, myocardial infarction, cell death among naive and memory T-cells, enhanced T-cell immunosenescence, posterior subcapsular opacities, increased hypertension, higher cholesterol levels, low HDL cholesterol, hypertriglyceridemia, aortic arch calcification, heart diseases, chronic liver diseases, (fatty liver, alcoholic liver disease and chronic hepatitis), uterine myoma and reduced hemoglobin levels, and heart diseases. Amongst the noncancerous disease deaths, deaths from heart disease and stroke contribute to more than half (54%) of all noncancer disease deaths.

Of the worst sufferers owing to radiations are pregnant women, fetus and new born children reported by myriad types of diseases as birth defects (babies born with a neural tube defects, microcephaly and microphthalmia), spontaneous abortions, less male birth ratio than that of female one, male fetus/neonatal death; reduction in RBC, WBC and platelet counts in children, increases in infant leukemia in the in utero exposure, miscarriages and stillborns, child born with mental retardation, decrease in IQ, pregnant mothers and fetuses are even more vulnerable to radiation effects and also develop different types of childhood cancers. It also influences growth rates and total life spans, and is associated with premature aging. The Japan's standard for radiation exposure for the general public is 1 millisievert (mSv) per year. The provisional standard for only Fukushima citizens is 20 millisieverts per year while the standard remained at the pre-accident level of 1 millisievert per year (mSv/yr) for all the other 46 prefectures of Japan [(173)]. The provisional standard for Fukushima applies to pregnant women and children, in spite of the vulnerability of fetuses and children to radiation. The 20-millisieverts-per-year figure is also the standard to decide the evacuation zone since any areas that are contaminated to the extent that living there will expose citizens to 20 mSv/yr or over are to be evacuated. In the case of in utero exposure (exposure of the fetus during pregnancy), excess cancers can be detected at doses as low as 10 mSv [(174)]. The BEIR VII committee has calculated the expected cancer risk from a single exposure of 0.1 Sv. The risk depends on both sex and age at exposure, with higher risks for females and for those exposed at younger ages. The committee predicts that approximately one individual per thousand would develop cancer from an exposure to 0.01 Sv [(175)]. Further, studies of cancer in children following exposure in utero or in early life indicate that radiation-induced cancers can occur at low doses. For example, the Oxford Survey of Childhood Cancer found a "40 percent increase in the cancer rate among children up to [age] 15. This increase was detected at radiation doses in the range of 10 to 20 mSv [(176)]. Since children are much more vulnerable than adults to the effects of radiation and fetuses are even more vulnerable. It is unconscionable to increase the allowable dose for children to 20 millisieverts (mSv). Twenty mSv exposes an adult to a one in 500 risk of getting cancer; this dose for children exposes them to a 1 in 200 risk of getting cancer. And if they are exposed to this dose for two years, the risk is 1 in 100. There is no way that this level of exposure can be considered 'safe' for children.

The general public, according to international regulations, it should not be exposed to radiation exceeds the average 1 mSv per year; meanwhile, nuclear workers in radiation areas receive ≤50mSv per year. Some studies [(161-164)] on liquidators or nuclear workers have reported long term adverse radiation related health effects and increased tendencies of developing cancers and non-cancer diseases.

Besides these, the immediate physical injuries as consequences of radiations entail deaths, infections, trauma and radiation sickness that includes nausea and vomiting, bruising and inability to heal wounds, bleeding out of orifices, bloody diarrhea and vomit, radiation burns, hair loss, headaches, weakness and fatigue, mouth sores, seizures and tremors, fever and infections (table 1) [(179)]. Moreover, the radioactive contaminants (radionuclides) associated with nuclear accidents and its long-term persistence in environment, are of great concerns in terms of health perspectives (table 2).

The world's largest nuclear accidents recorded so far: accidents at Chernobyl, Three Mile Island, and last in Fukushima, have made us more worried about the safely uses of nuclear power, and opened the chapter of many debates and controversies about the usage and utilization of nuclear energy since the epidemiological studies (table 3) suggest that not only the pregnant women, fetus and children are susceptible to radiation induced effects, but, in realism, it also affects all ages of people; in other words, its affect from embryo or fetus to all classes and ages of people though severity of the health effects of nuclear radiation depends on several factors (number of cumulative radiation exposure, the distance to the source of radiation and duration of exposure to radiation, ages and sexes). It is matter of deeply thought that will it be possible for developing countries (due to increase in nuclear power plants) (165) to secure the lives and health of her people during any unexpected nuclear detonation or accident since she itself suffers from lack of resources, education, consciousness among people, shelters and emergency medical preparedness while the developed countries are feeling insecurity from nuclear accidents? Now, the time has come to rethink profoundly over radiation mediated health hazards by principally focusing international health which requires urgent public awareness among each and every nation of both developed and developing countries throughout the world.

Table 1. Signs and symptoms of acute radiation sickness after exposure.

Prodrome in Accordance with Exposure Level	Latency[a]	Illness[b]
Mild (1 to 2 Gy) Vomiting; onset, 2 hr	Duration, 21–35 days; lymphocyte count, 800-1500/mm^3	Fatigue, weakness; mortality, 0%
Moderate (2 to 4 Gy) Vomiting, mild headache; onset, 1–2 hr	Duration, 18–35 days; lymphocyte count, 500–800/mm^3	Fever, infections, bleeding, weakness, epilation; mortality, ≤50%
Severe (4 to 6 Gy) Vomiting, mild diarrhea, moderate headache, fever; onset, <1 hr	Duration, 8–18 days; lymphocyte count, 300-500/mm^3	High fever, infections, bleeding, epilation; mortality, 20–70%
Very severe (6 to 8 Gy) Vomiting, severe diarrhea, severe headache, high fever, altered consciousness; onset, <30 min	Duration, ≤7 days; lymphocyte count, 100-300/mm^3	High fever, diarrhea, vomiting, dizziness, disorientation, hypotension; mortality, 50–100%
Lethal (>8 Gy) Vomiting, severe diarrhea, severe headache, high fever, unconsciousness; onset, <10 min	No latency; lymphocyte count, 0-100/mm^3	High fever, diarrhea, unconsciousness; mortality, 100%

[a]Lymphocyte counts in the latency phase represent the range of values that may be seen 3 to 6 days after radiation exposure.
[b]Mortality estimates are for patients who do not receive medical intervention.

Table 2. Main biokinetic characteristics of some long-lived radionuclides.

Radionuclide	Main Emission	Physical Half-Life (Years)	Biological Half-Life[a]	Gut Transfer Factor (F1)	Distribution in Body Target Organ
^{36}Cl	Beta	3×10^5	10 Days	1	Uniform
^{79}Se	Beta	1.1×10^6	Triexponential elimination, with Half lives of 3 (10%), 30 (40%) and 200 (50%) days	0.8	Fairly uniform, kidney
^{94}Nb	Beta, Gamma	2×10^4	Biexponential elimination, with half lives 6 (50%) and 200 (50%) days	<0.01	Lung, Skeleton, liver
^{99}Tc	Beta	2.1×10^5	0.5 days in the thyroid 75% of the technetium retained in the thyroid is eliminated, with a biological half life of 1.6 days	0.5	Fairly uniform, thyroid, salivary gland, gastrointestinal tract (GIT)
^{129}I	Beta	1.57×10^7	80 days in the thyroid	1	Thyroid
^{135}Cs	Beta, Gamma	2.3×10^6	Biexponantial elimination, with half lives of 2 and 110 days	1	Fairly uniform
^{238}U	Alfa, Gamma	4.47×10^9	100days	0.02	Skeleton, kidney
^{239}Pu	Alfa	24,130	10 years in the liver, up to several tens of years in the skeleton	5×10^{-4}	Liver, skeleton, gonad

a = Time after which one half of the element is eliminated by biological pathway.
F1 = The fraction of ingested substance that is directly absorbed and passes into body fluids.

Table 3. Major nuclear power plant accidents and their effects.

Date	Location	Causes	INES Level	Effects
11th March, 2011	Fukushima Daiichi Power Plant Explosion Fukushima, Japan	Cooling failure in 4 reactors following an earthquake tsunami and multiple fires and Hydrogen explosions	7	Release of radioactive Iodine-131 and Caesium-137; vegetables, fish, food & water contamination; mental stress, minor radiation sickness, 2 deaths
26th April, 1986	Chernobyl disaster, Ukraine, USSR	Steam explosion and fire	7	Major release of radioactive material (iodine-131, caesium-137, tellurium) with widespread health and environmental effect; radiation sickness; perinatal mortality and trisomy 21; fetus/neonatal death; Hair loss, sterility, bone marrow destruction, internal bleeding and immune system failure; leukemia; babies with a neural tube defects; 57 direct deaths; 6,000 thyroid cancer fatalities from contaminated milk
28th March, 1979	Three Mile Island Accident, Middletown, Pennsylvania, USA	Loss of coolant and partial core meltdown	5	Major radioactive release including gases (xenon-131) and iodine-131; cancers; lung cancer; leukemia; erythema, hair loss, vomiting, and pet death; psychological implications, miscarriages and stillborn; zero deaths

INES (International Event Scale): Level 7 = major accident; level 6 = serious accident; level 5 = accident with wider consequences; level 4= accident with local consequences; Level 3 = serious incident; 2 = incident; 1 = anomaly; level O = no safety significance

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