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Study on the impacts of radioactive radiation on female's health: A brief review report

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ABSTRACT

Radioactive radiation is a part of natural background radiation. Every object in earth is continuously exposed by this radiation. Knowledge about the health risks associated to radioactivity is important to protect our lives and to review the protective guidelines. Generally, the risks of incidence of some health effects including cancers are somewhat higher for females than males. To observe the present status of the radioactivity-induced diseases in females, the present study reviewed briefly the occurrence of some health problems on females. It is found that the female's organs are more sensitive to radioactive radiation than males for causing acute health diseases including cancers. This study cannot find a definite answer regarding the reason of increased harmful effects on women's health due to radioactive radiations. The developing tissues are more sensitive to ionizing radiations; therefore, the effective damages in these tissues may appear quickly than others. Additionally, hormonal differences between women and men may have some impact on the enhanced radio sensitivity to women. Other unknown influencing factors related to human biology may greatly present in females than males, and thereby some of these factors may also be assumed to be responsible for occurrence of some harmful effects significantly in females. Statistical data concerning the different health risks to females who are unintentionally exposed by natural environmental radioactivity are lacking. More systematic studies are required in future to elucidate the gender dependent radio sensitivity from fetus age to old age, and to ensure the people of different ages are equally protected from radioactivity.

KEYWORDS: Radioactivity. Modes of radiation exposures.Radioactivity-induced diseases. Female's health status.

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INTRODUCTION

Naturalbackground radiation occurs at varying intensities all over the environment. There is nowhere place and object including human body on the earth that one can get away from the exposure to background radiation.The natural background radiationincludes cosmic radiations, primordial radiations, and radiations from cosmogenic radioactivity[1]. Cosmicradiation is the earliest source and emerges at the formation of the universe. This radiation is the collective of the high-energetic particles that originated from the sun and from outside the solar system[11]. Primordial radionuclides created with the formation of the earth, and these are ^{238}U, ^{232}Th radionuclides and their corresponding decay progenies, andalso natural ^{40}K radioisotope[2]. The third source is the cosmogenic radioactivity resulting from the interactions of the cosmic radiation with the atmosphere in a continuous manner. The cosmogenic radionuclides are mainly ^{3}H, ^{7}Be and ^{14}C.[3]Occasionally, people are exposed by another type of radiations that emitted from several anthropogenic sources, such as fallout from accidental releases, debris from weapons tests, and releases from the nuclear reactors and fuel cycle[1].

Among the above mentioned radiations, the radioactive radiation is a type of ionizing radiation(IR), and it is emitted from a radionuclide which is an energetically unstable nuclide.Effectof the radioactive radiations is a complete carcinogen for human population, because they can cause significant biological effects on the human body and weaken the body genetic materials. The natural radionuclides of the decay series (mainly, ^{238}U and ^{232}Th decay series) are ubiquitous in the earth's crust; and ^{40}K, ^{14}C and other radionuclides are present in living cells themselves[18]. On the other hand, artificial or human-made radioisotopes such as ^{134}Cs, ^{137}Cs, ^{90}Sr and ^{131}I are generated by a number of human activities[4], which are atmospheric nuclear weapons testing, nuclear reactor, non-nuclear industries such as building materials and fertilizers industries,particle accelerators, materials used in medicalexposures, and occupational exposures[3, 5, 41]. So, the common people is continuously exposed by the radioactive radiations with varying intensities directly or/and indirectly.

Air, water, and soil are the basic indicators of the environmental radioactivity, because they act as the sources of transfer of radionuclides intothe human body through the air-plant transfer process[14] and soil-plant transfer process[13].When the radioactive materials are entered into the human body, the emitted radiations, mainly alpha and beta radiations can interact with the atoms or molecules of the body cells, and gamma rays can easily pass through the entire body without interacting. However, ICRP (International Commission on Radiological Protection) reported that theionizing radiations such as alpha and beta particles, and gamma rays can directly and indirectly alter the normal structure of living cells[19]. Uranium is an alpha emitter; it has both chemical and

radiological toxicitiesand affects mostly kidney and lungs[55].Beta emittersuch as ^{90}Sr, can accumulate in the bones and increases risksto humans[78]. Alpha particles have strong ionizing power so that they have larger ability to cause double strand breaks of DNA (Deoxyribonucleic acid)[74],and can disrupt the DNA inside cells, which leads to cell damage and cell death[61]. TheDNA chromosome damage by alpha particle radiation is 100 times more than by exposure of DNA to other types of radiation[12]. If double strand breaks are not repaired by the natural biological process of human body, it may lead to increased frequency of chromosomal aberrations, mutations and carcinogenesis[41].

The radio sensitivity of different human subpopulations is influenced by differentdemographic factors which are sex, age, genetic susceptibility, co-morbidities, and a variety of other lifestyle factors[47].A very less attention has been found in literaturesregarding the influence of gender differences on radioensitivity to human. ICRPhas based its recommendations on a population average, rather than the data on the radio sensitivity of different subpopulations[47].The report on biological effects of ionizing radiation (BEIR)[6], emphasized that the risk of suffering and dying from radiation-induced cancer is greater for women than for men, even for the exposure to the same dose of radiation to them[47].It is observed that female breasts are more sensitive to ionizing radiation, while men can develop breast cancer is extremely rarewith an incidence about 0.01% of the female's breast cancer[66].

Therefore, increasing attention has been paid on the effects of radioactive radiation on female's health, because the female reproductive health is one of the great significance for familial and social harmony[17]. Blot and Sawada referred an article, where it was mentioned that the Nagasaki women who were pregnant at the time of atomic bomb explosion, the excessive fetal loss and infant mortality were found among those women who were heavily exposed by the radiations resulting from the explosion[67].So, it can beexpected that girls who have exposed unintentionally by the environmental radioactive radiation for a long-time period,they may survive later from various radioactivity-induced diseases, e.g., the high risk of ovarian failure, which results in future in the increase of infertility, occurrence of the stillbirth and low birth weight among offspring.

Humanoocyte, a female gametocyte or germ cell, is exquisitely sensitive to ionizing radiation[9, 17]. When the radioactive materials are entered into a pregnantwoman, theseare absorbed into her bloodstreamandmay thentransportfrom the mother's blood to the fetus or baby through the umbilical cord,orevenconcentrate in nearby areas of the mother's womb such as the urinary bladder. Finallythe fetus or babyisexposedby the radiations emitted from the transported radioactive materials; this was concluded by ICRP[42]. The exposure of a fetus to radiation,called prenatal radiation exposure, canalso occur when the mother's abdomen is exposed to the external radiation. Radiation exposure before birth can increase a person's risk of getting cancer later in life[75].So,

exposureof the embryos or fetuses to radioactive radiation is of immense concern for radiological protectionand health.Additionally, the magnitude and type of risksassociated with radiosensitivities to the children and mothers must be known to prevent the health consequences of exposure to such radiations. Until now, limited number of published articles has been found regarding the health effects on female or women due to the natural radioactive radiations.Reflections on the impact of advances in the assessment of genetic risks of exposure to ionizing radiation on international radiation protection recommendations were undertaken by SankaranarayananandWassom[38].

The objective of this study isto comprehensively and systematicallyreview the health diseasesof females or women due to radioactivity and to observethe association between thenatural radioactive radiation and the female's health conditions at present.

MODES OFEXPOSURETORADIOACTIVERADIATIONS

People are commonly exposed by two principal modes of exposure, namely, internal and external. Another type of exposure is contact exposure, but it is rare.

Internal exposure occurs when the source is presentinto the human body. Internal exposure due to radioactivity occurs usually as a consequence of the ingested or inhaled radioactive materialsthrough the consumption of air, water, and foods. For examples, ^{14}C is absorbed by vegetation, ^{40}K is found in the soil, and traces of uranium, thorium and their descendants can be found into soil, foods, and drinking water[46]. After consumption, different radioactive elementscan be deposited in several organs with different amountsdependingupon the metabolism of the radionuclides[52]. For example,uranium is deposited inkidney, lungs and soft tissues[54 – 55],whereas thorium is deposited in skeletal tissues and liver[53]. The trace quantities of radon gas, another descendant of uranium, can be entered into lungs through the inhalation process,and its radioactive descendants sometimes fix themselves to bronchi in the lungs and damaging the basal cells of the lungs tissues by exposure toalpharadiation[9, 30].

Externalexposure results from the radiations emitted from those sources which are located apart from the human body. Cosmicrays, radioactivity of rocks, gamma rays, andoccasionally X-rays, are mainlyincludes in the external radiations. If the radioactive elements remain fixed at outside the body, radioactivity does not provide relevant information as to comparative danger. But, when the radioactive contaminants spread throughout the environment, then it is more concern for human population as well as animals. It is reported that the health consequences of the Chernobyl disaster have shown a significant increase in the risk of thyroid cancer among children and adolescents living near the reactor[70 – 71]. The increased risk has been definitively linked to the quantities of ^{131}I, ^{134}Cs

and ^{137}Cs isotopes,which were released from accident of the Chernobyl nuclear reactor to the surrounding environments[18, 76].

It may be noted that ^{131}Iisotope provides an effective illustration of the different risks associated with internal and external exposure. However, the internalexposureis the most harmful than the external as the sourcesthat trapped in the human body can stay there for long time, and working over very small distances inside the body.

EFFECTS OF RADIOACTIVE RADIATIONS ON HUMAN POPULATION

For general public

If the radioactive materials are present in the human body, the emitted radiations from these materials can severely damages the body cells by disrupting the atomic structure of themoleculesof the cells.Damagedcells that survive may then induce carcinogenesis or other abnormalities in human organs through gene mutation and chromosome aberration[56 – 60].The affected organisms have the ability to compensate the biological damages like loss of cells, if the harm appeared as temporary; otherwise,the cellular damages may lead toincrease the possible risk of cancer, particularly in the developing tissues. Unlike cancer, the effects of radiation exposure causingthe radiation sickness, which includes symptoms like nausea, vomiting, hair loss, diarrhea,skin burns, hemorrhage, destruction of the intestinal lining, and central nervous system damage. However, the effects of radioactive radiations on human health depend on the time duration of exposure and intensity level of the radiations.

Health effects of human due to exposure to ionizing radiation are generally classified as deterministic and stochastic[21, 25].

Deterministic effects are also called non-stochasticeffects or tissue reactions. These effects are characterized by a threshold dose,andbelowthe threshold dose there seems to be no risk of the effectsto a person[21 – 22]. These effects can usually appear within a day or after a few weeks if the exposure is taking with high-level for short-time;or, appear after a month or quickly than a year if the exposure is taking with low or high levels and long-time. If dose is high asover $0.5\ Gy$,the damage is sharply predictable, reproducible, and highly widespread; the severity response of these effects isnormally seen with increasing doses of radiation[48]. Deterministic effects are differentiating in two types – the acute radiation sickness and the chronic radiation sickness. Acute radiation effects are early-responding, and occur mainly when the radiation exposure is high-level and short-time. These effects occur just after exposure or within 24 hours, these are curable or controllable. The acute radiation sickness includes nausea, vomiting, diarrhea, headache, fever, hair loss, and the skin and tissue burns[16]. On the other hand, the chronic radiation sickness is late-responding and occurs when

the exposure is taking with low or high levels and continues over many years. The chronic radiation effects are dangerous and non-curable, and sometimes reach to chronic level that may lead to death of a large number of cells and may later induce some chronic diseases such as cataract, cancer, genetic mutation, temporary and constant sterility, and instability to conceive baby[16].

Stochastic effects occur when a person received a high dose of radiation. The result of these effects is some of the changes may persist in daughter cells but not killed. These effects occur by chance usually without getting a threshold dose. For low or medium-strength doses radiation exposure, the effects are not as clear-cut and predictable immediately. Their probability of appearancedepends on the dose-rate and follows a simple, linear-non-threshold (LNT)model, which is the basis for current radiation protection standards and practices[7, 23]. The severity does not depend on the magnitude of the absorbed dose. For the same absorbed dose, it is found that the densely ionizing radiations such as alpha particles are more effective in causing biological effects (especially stochastic effects) than gamma rays, X-rays or electrons[9]. The stochastic effects include the somatic stochastic effects and the genetic or hereditary effects. Stochasticeffects are the cancer development in the exposed individuals if the mutation occurred in the somatic cells (somatic effect), and are the hereditary diseases in the offspring of individuals exposed if the mutation occurred in thereproductive or germ cells (genetic effect)[8]. Somatic effects are malignant and harms (cancers) for individuals and the exposed individuals suffer during their lifetime. The genetic effects are transmits throughout the generation. The gene mutation and DNA damage are including in the genetic effects[7]. It is observed that prolonged exposures of the low level radiation can cause acute health effect on the consumers, evidence of an increased cancer risk in humans is available at doses above 100 mSv [8, 15].

It is important to remember that not all organs of a human body are equally affected by the ionizing radiations, but the effects are depending on the radiosensitivity of each organ and also the age of the human body. The developing human brain has been shown to be especially sensitive to ionizing radiation[9]. Reproductive organs such as the male gonads are more than 20 times sensitive to skin. The frequency of breast cancer of women increases with age and the radiosensitivity of the breast decreases with age[9].

For females or women

Many studies have been found that a number of major illnesses in human body are influenced by gender. This holds true for the potential risks associated with exposure to radioactive radiation or other ionizing radiations. Added radiation may increase the health risks to human. National Academy of Sciences (NAS)[6] report is stunning enough; it finds that harm (cancer) to women causes by radiation is 50% higher than the comparable harm to men from ionizing radiation of same doses. Themost common cancers that appeared among men are lung, colorectum, stomach, prostate and

liver cancers; and that appeared among women are breast, lung,cervix, thyroid, colorectum, ovarian and stomach cancers[26, 70 – 71].Effects of radiation can result in the reduced immunity, pregnancy loss, and the infertility in women.Irradiation during gestation of women is associated with some health problems such as functional impairment, and also increasedthe other diseases such asneurobehavioral abnormalities, heart diseases, birth defects with heart defects, as well as other mutations (both heritable and not), fetal growth disorders, congenital malformations, and malignant diseases in offspring. Possibility of these health problems depends on the gestational age of the fetus at the time of exposure and the amount of radiation it is exposed to.

The developing organism such as prenatal development, which is characterized by intensive cell proliferation, cell differentiation, and cell migration, is highly sensitive to radiation. Fetus with its rapidly dividing cells is particularly sensitive to the radioactive radiation during their early development[62], between weeks 2 and 18 of pregnancy[75].When damage is catastrophic to a developing embryo, the spontaneous abortion or miscarriage of a pregnancy may appear.

Riskof the breast and ovarian cancers from radiation is high in case of women, but the radiation causes breast cancer in menis extremely rare[63 – 64]. UNEP have also reported that girls whose age at under 20 years, they are about twice as likely to induce breast cancer resulting from ionizing radiation than adult women[26].Females are also seen to have a higher risk of theradioactivity-induced thyroid cancer than males[70 – 71].

METHODS

This study searched published research articles, review reports, including PubMed databasethat contain the data or information relevant to the incidence health risks due to the radioactive or other ionizing radiations to human population. This is required for making the present study successfully. Most of these studies are published in different valuable national and international repute journals and books from 1972 to April, 2019. From these studies, the required information and supporting data can be usedto obtainthe status of the radioactivity-induced diseases or health problems of females at the present time. A few reference lists in the research articles and review articles are also taken to identify the additional relevant publications.

The obtained published studies have been written and published in English and have the sufficient data on the relationship between the radioactive radiationsand the health diseases of females.

Global scenario on the radioactivity-induced health effects in female population

In this section, introducing some significant issues in how the radioactivity of different sources induces harmful effects on female population.

A study on the female's breast cancer that was incidence during the period of 1950 – 1969 after the Hiroshima and Nagasaki atomic bomb explosion (9th August, 1945) in Japan was undertaken by McGregor and group[69], they have been identified 231 cases breast cancer among 63,275 female survivors. They have suggested that carcinogen effect of the neutron and gamma radiations on the breast tissue inducing the breast cancer.

Exposure of pregnant women to ionizing radiation has been studied in several populations including the survivors of atomic bomb blastat Hiroshima and Nagasaki[62].Thispopulation based studyfound an increased incidence of breast cancer in female survivors. The study reported that women who were exposed during their pregnancy, they have suffered from the increased incidences of stillbirths, miscarriages, and neonatal deaths. The study also reported that children survivors have been suffered fromcongenital defects. A similar study was conducted by Land and group, regarding the incidence of female breast cancer among the survivors[65]. They infer that exposure at before age 20 years of females who survived from breast cancer are associated with higher excess relative risk (ERR) (1 Sv) compared to the exposure at older ages.So, the acute health effects have been found in the pregnant and non-pregnant women as well as children survivors.

Several other studies have been involved on the effects of Hiroshima and Nagasaki atomic bomb blast. In a life span study on the survivors it is observed that the ERR estimates for cancers were significantly higher in women than in men, and the ERR of the total deaths and all solid cancer due to ionizing radiation exposure is found as nearly twice times high in females than in males[68]. The increased risks to the cancers of gallbladder,ureter and renal-pelvisoccurs in malesonly, whereas the cancers of rectum, stomach and other digestive diseases showed increased radiation risk in females only. This life span study also found the significant increases of malignant lymphoma mortality for males only, but multiple myeloma for females only.Preston and coworkers[51] have been reported that the increased risks for solid cancers vary with gender. In a case-control study, conducted by Hill and group[64] among young women, it is mentioned that the medical radiation exposures at before age 20 years of females are associated with the slightly increased risk of breast cancer regardless of their family history of breast cancer, whereas the increased risk of breast cancer in theolder womenis observed only the women havea positive family historyof breast cancer[64]. So, the risk of breast cancer is not only increased with radiation exposures but also increased significantly with the family history of breast cancers. Added ionized radiation can be enhanced the probability of occurrence of some chronic diseases like the breast cancer.

A study, on the effects of ^{137}Cs and ^{134}Cs radioisotopes which were released from the accident of the Fukushima Daiichi Nuclear Power Plant (NPP) in Japan, was conductedbyEvangeliouet al.[37]. They have been mentioned that the lifetime attributable risk (LAR) is

higher in female infants (> 14 in 10,000) and lower for 10-year-old male children (< 4 in 10,000) in the territories of the Fukushima NPP. A pediatric oncologist at Jikei University School of Medicine has tested lingering exposurestocaesium radioisotopes on the pregnant women and children in Kouri town, adjacent to Fukushima City, and the oncologist found that one in hundred has received a dose higher than worldwide background radioactivity levels. This was reported by Pacchioli[24].

The possible health risks associated with human exposure to radiation from damaged reactors at the Fukushima Daiichi nuclear power station (NPS) were assessment by Walsh and co-workers[79]. Their estimated results shown that the LAR to solid cancers in females (ranged from0.1×10^{-2} to 0.7×10^{-2}) is higher than in males, depending on age group. Thelifetime baseline risk(LBR)to leukemia is smaller for females ($\approx 0.4 \times 10^{-2}$) than for males ($\approx 0.6 \times 10^{-2}$). For the thyroid cancer, LBRin females ($\approx 0.8 \times 10^{-2}$) is about 4 times greater than in males ($\approx 0.2 \times 10^{-2}$), and LARin females isabout 5 times greater than in males. The LAR in case of female breast cancer is greatest after exposure at 1 year of age and become progressively smaller with increasing age at initial exposure.

Radiation dose rates in three areas neighbouring the NPP were evaluated by a group of researchers[44]. Thelifetime risk for the incidence of solid cancer has been found as higher inthe females and infants than inthe males. They have been found the highest relative increased risks of solid cancer, leukemia, and breast cancer as 3.3% in female infants, 4.6% in male infants, and 4.5% in female infants, respectively.Comparedto the LBR of these three types of cancers, they have alsobeen found as 6.5% for female infants, 13.6% for male infants, and 27.5% for female children, respectively.

The Chernobyl nuclear reactor accident (April 26, 1986) is a catastrophic nuclear accident, by which the territories nearby the reactor were badly contaminated by the radionuclides released from the reactor. Narendran and group have been reported that womenof the radioactivecontaminated areas in Ukraine, located at the territory of the reactor, developed thyroid cancer 2.5 times more than men; it wasmentionedin the cases of thyroid cancers registered from 1998 to 1999 .[47]This group hasshowed that the sex-related factors may potentially influence the long-term response to radiation exposure;additionallythe long-term radiosensitivityto females is higher than that to males. A detail analysis of the populations exposed to the Chernobyl fallout also revealed changes in the sex ratio, early mortality, Down's syndrome, and other genetic alterations. After 1990, a similar trend wasobserved by Yablokov et al. in Russia and Czech Republic where the women were at a higher risk of developing thyroid cancer than men[49]. In Belarus, near the reactor, there is found a 1.5- and 2-

fold increase in lymphatic and hematopoietic cancers in women and men, respectively, during the first 5 years after the Chernobyl disaster[49]. The overall cancer incidence rates in Belarus are higher in women (18% per year) than in men survivors (4.4% per year), and overall the rates ofbreast cancer incidence wereincreased from 1745 to 2322 cases between the years of 1986 to 1999[49].Also, the incidence of breast cancer was considerably increased in women living in the territories which contaminated with ^{137}Cs radioisotope during 1990–2003[49]. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported that the release of ^{131}I, ^{134}Cs, and ^{137}Cs radionuclides from the Chernobyl nuclear reactor were adversely affects the individuals of the territories of the reactor[76]. The association between thyroid cancer and ^{131}I radioisotope has been confirmed as ^{131}I radioisotope is mainly concentrates in the thyroid gland[26].

Sonowal and Jojo[72] mentioned a survey report regarding the Jaduguda Uranium Mine, their survey report revealed that the women folk in the locality of U-mine complaint about certain reproductive healthproblems which may be caused by the radiations resulting from the contaminations of Jaduguda Uranium Mine. For instance, 47% women reported disruptions during theirmenstrual cycle, 18% women reported miscarriages or still birthin last 5 years, 30% reported some sort of problem inconception, andmajority of women complained of fatigue,weakness and depression. Among the 66 sufferer in and around Jaduguda, the number of suffered persons particularly in case of TB (tuberculosis) are far greater among the males (~ 33.33%) than females (~ 3.03%). The local women also reported that the 51 children in and around the U-mine area were suffered from different types of ailments and 38, i.e., above 74%, among children were suffered from disabled and crippled diseases. Similar study has been undertaken by Thakur and Sapra[73]. They have mentioned a study that says 9.60% of women were unable to conceive baby even after 3 years of marriage.They have been found complaint on the occurrence of the infertility and congenital anomalies on the females of ages above thirteen years. Besides, some diseases like child death, intra uterine deaths, premature birth, spontaneous abortion, etc. are also found among females.They have also mentioned that themost common complaint of among females was the leucorrhoea (3.4%).Another study was conducted by Lourenço et al. on the deactivated uranium mine at Cunha Baixa[10], they have collected blood samples individualsnearthe deactivated U-mine. This study reports thesignificant differences have been observed in total WBC (white blood cell) count of females of ages bellow 40 years. This shows an increase in WBC infemales at the control and contaminatedsites of the Cunha Baixa village. The same wasobserved for neutrophils in the same individuals.

A study regardingtheworkers in the nuclear industry throughout the United Kingdom, as well as British Nuclear Fuels was conductedby Doyle and group[50].They havereported thatthe 2.6% of men and 3.7% of women workers undergo primary infertility. The authors observed that there is associationbetween the low level radiation exposures and the increased primary infertility in women, but the same is notfound in case of men.They also mentionedby referred an article that an increased risk of fetal lossis observed in the pregnant female workers.In case of Chernobyl emergency workers, UNSCEAR recognized that there is an increased incidence of cataracts among the workers. Studies since 1986 shows that the persons who were exposed as children to the ^{131}I radioisotope and the workers who possibly associated high doses of radiation exposure, they are now suffered at increased risk to induceradiation effects[26].

The lifetime risk of lung cancer attributableto continuous life-long exposure to indoor ^{222}Rn at a concentration of 150 $Bq.m^{-3}$ was estimated by National Academy of Sciences[29] for men and women, and found risks as 3.4% and 1.4%, for men and women, respectively.The value of 150 $Bq.m^{-3}$is the EPA guideline for maximum acceptable ^{222}Rn concentration in indoor air. But, in another study that was undertaken by Jarrahi and group[43], they have reported that a higher mortality rate is found in female residents of high background natural radiation areas than in residents of normal background radiation area. They infer that this is attributed to the higher indoor radon dose, because, most of the female residents remain indoors. Also the study revealed that there is no evidence of the increase in incidence or mortality among the male population.Another study reports the alpha-radiation emitted from the radon gas can damage both male and female reproductive systems, and aggravate the infertility[40].

The study of regional patterns of thyroid cancer incidence in relation to iodine intake and iodination in Sweden revealed that residence in iodine-deficient regions isrelated with a 2-fold increased risk of follicular cancer in case of men (relative risk 1.98) and a 17% increase in case of women (relative risk 1.17)[31]. The occurrence of thyroid cancer differed slightlyin some regions, suggesting that the observations in these regions defined by iodine intake were unlikely to be artifactual. They also suggest that iodination of the food supply is not related in the occurrence of thyroid cancer.

Levels of the natural and artificial radioactivitiesin six types of fishes consumed in Hong Kong have been determined by Yu and co-workers[35]. They estimated the committed effective doses due to intake of radionuclides through the consumption of such fishes, and found as $\mathbf{1.2}$ (male) and $\mathbf{6.4}$ (female) $\boldsymbol{\mu Sv.y^{-1}}$ for natural radionuclides, whereas $\mathbf{0.027}$ (male) and $\mathbf{0.026}$ (female) $\boldsymbol{\mu Sv.y^{-1}}$ for artificial radionuclides. This suggests that the radiosensivity of natural radionuclides to women is higher than men.

Reproductive and developmental toxicity of natural and depleted uranium has been reviewed by Domingo[45]. Domingo mentioned that the effects of uranium toxicity can be decreased fertility, embryo or fetal toxicity including teratogenicity, and also the can be reduced growth of the offspring at different gestation periods of women. Here, the uranium causes reproductive toxicity, maternal toxicity, and the postnatal effects of uranium are also reviewed.

The environmental monitoring of radon in the blood and urine samples of females with the cancer problems has been carried out by Salih and co-workers[36] for the purpose of health risk assessments. Their estimated results showing the radon concentration in urine samples is larger than that in blood samples. They infer that the radon concentration in the samples of blood and urine of women of the exposed group is higher than those of the control group. The significant of the results in this study showingthe association betweenthe radon concentration of blood and urine and the cancers.

Concentrations of the accumulated ^{40}K, ^{137}Cs, ^{210}Pb, ^{226}Ra, ^{228}Ra, and ^{228}Th radioisotopes in human teeth due to environmental contaminants at different states in the Northern Malaysian Peninsula were estimated by Almayahi et al.[33], the concentrations of the radionuclides are higher in female teeth than in male teeth. Sogut et al. [39] have shown that the mean activities of the gross alpha and gross beta of the tooth samples of female age-groups vary between $0.534 - 0.203\ Bq.g^{-1}$ and $0.010 - 0.453\ Bq.g^{-1}$ and that of male age-groups vary between $0.009 - 1.168\ Bq.g^{-1}$ and $0.071 - 0.204\ Bq.g^{-1}$. The radiobiological analysis of natural alpha emitters in human teeth of people in Malaysia was done by Almayahi et al.[34], they have observed that the average value of the emission rate of alpha particles from the male teeth is greater than that fromthe female teeth. On the other hand, a case study was undertaken by Taskin and group[32]to determine the activity levels of gross alpha and gross beta in human teeth of Istambul, Turkey. The determinedradioactivity level in the tooth samples of males is higher than those of the females.

To assess the impact of alpha-emitters on women fertility, Salih and Jaafar[40] collected 30 biological samples of uterine tissues from both the female cancer patients and the women with fertility problemsin Iraqi Kurdistan region. They have mentioned that the alpha-radiation emitted from the radon gas can damage both male and female reproductive systems, and aggravate the infertility. This study determined the concentration of alpha-emitters in these tissue samples and found as $0.0180\ ppm$ to $0.0691\ ppm$ with an average value of $0.0330\ ppm$.

Williams and Fletcher[20] have been studied on the risks of prenatal exposure to ionizing radiation during pregnancy of women[20]. They have been reported that the fetus is most susceptible to radiation during organogenesis (2 to 7 weeks after conception) and in the early fetal period (8 to 15 weeks after conception). The possibility of growth restriction, spontaneous abortion and mental

retardation may occur at higher exposure levels.Non-cancer health effects have not been detected at any stage of gestation after exposure to ionizing radiation of less than $0.05\ Gy$.

Based on the simple additive risk model[27] and simple multiplicative risk model[28], Upton and co-workers have been estimated the lifetime attributable risk of cancer to $0.1\ Sv$ of whole-body irradiation, and found $20-40$ number of females out of $100{,}000$ can be died due to breast cancer[18].

DISCUSSIONS

From the above mentioned studies, it is observed that a significant number of research groups have been involved on the radioactivity-induced diseases which are appeared from the results of various sources such as the nuclear disaster, nuclear industryand mining, but the statistical data concerning the different levels of health risks to human population including females who are unintentionally exposed by the natural environmental radioactivity are lacking.

The different health diseases that occurred in females and women due to the effects of the atomic bomb blast, nuclear reactor accident, mining, nuclear industry, radon exposure, uranium toxicity, and the other environmental contaminating agents are summarized in Table 1. A large number of adverse health effects occur in people of the Hiroshima and Nagasaki, Fukusima Daiichi NPP and Chernobyl nuclear reactor, and their territories after the disasters.It is seen that the females are suffered mostly from the breast cancer, thyroid cancer, solid cancer, cancers of stomach and rectum,multiple myeloma,and theother health problems such as infertility, miscarriages, ovarian failure, and stillbirths. On the other hand, male persons are suffered largely from TB and leukemia than the female persons. So, the incidence risks to TB and leukemia due to the radioactive radiations or other ionizing radiations are more sensitive for males than for females.

Female survivors of the Hiroshima and Nagasaki and its territories have been suffered mostly from the increased incidence of the breast cancer, multiple myeloma, solid cancer, cancers in stomach and rectum. The miscarriage, stillbirths, and neonatal deaths occurred among women who were exposed during the pregnancy period. It is mentioned in the literatures that younger females of ages around 20 years, they have higher excess relative risk (ERR) of radiation-induced breast cancer than the older women. Women of age more than 50 years have not suffered from the measurably increased risk of the radiation-induced breast cancer[63].

Table 1: Some radioactivity-induced health effects on females mentioned in literatures

Sl. No.	Health effects occur on female due to radioactivity	Sources of radiations	References
1	Breast cancer, cancers of stomach, rectum and other digestive diseases, increase of multiple myeloma, increased incidences of miscarriages, stillbirths, and neonatal deaths, congenital defects.	Hiroshima and Nagasaki atomic bomb explosion	[62 – 65, 68 – 69]
2	Lifetime attributable risk (LAR) for solid cancer, breast cancer, and thyroid cancer.	Accident of Fukushima Daiichi Nuclear Power Plant	[37, 51, 79]
3	Thyroid cancer, breast cancer, solid cancer, changes in the sex ratio, early mortality, Down's syndrome, and other genetic alterations.	Chernobyl nuclear reactor accident	[47, 49]
4	Cancers, disruptions during the menstrual cycle, miscarriages or still birth, unable to conceive baby, fatigue, weakness and depression, birth defects, cancer, child death, intra uterine deaths, premature birth, spontaneous abortion, and leucorrhea, significant differences in WBC count.	Uranium Mine	[10, 72 – 73]
5	Primary infertility, increased risk of fetal loss.	Nuclear industry, Nuclear Power Plant	[26, 50]
6	Lung cancer, damage of reproductive systems, infertility, and higher mortality rate.	Exposure to indoor ^{222}Rn isotope	[29, 43]
7	Thyroid cancer, follicular cancer	Iodine intake and iodination	[31]
8	Dose received from natural radionuclides is higher than that from artificial radionuclides	Natural and artificial radionuclides in some fishes	[35]
9	Decreased fertility, embryo or fetal toxicity including teratogenicity, and reduced growth; reproductive toxicity, maternal toxicity, and the postnatal effects.	Natural and depleted uranium	[45]
10	Radionuclide concentrations were found higher in female teeth than in male	Human teeth	[33]
11	Infertility, damage of reproductive systems	Alpha emitters in uterine tissues of female cancer patients and women with fertility problems	[40]
12	Cancers, spontaneous abortion, growth restriction, and mental retardation	Exposure to ionizing radiations such as gamma rays	[20]
13	One in hundred women has received a dose higher than worldwide background radioactivity levels	Lingering exposures to caesium radioisotopes	[24]

After the accident of Fukusima Daiichi Nuclear Power Plant (NPP), the different types of cancers like solid cancer, leukemia, and breast cancer are mostly occurred in the individuals of its nearby areas. The lifetimeattributable risks(LARs) and lifetime baseline risks (LBRs) to the solid, thyroid and breast cancers are found higher for females and infants than for males[79]. The LAR and LBR for females are 5 and 4 times greater than for males survivors, respectively[79]. Peoplewho were exposed to ionizing radiation at the age of 30 years, and after became ages of 70 years their solid cancer rates increased by about 35% per Gy for men and 58% per Gy for women[51].Many researchers have been mentioned that these are due to the exposures to caesium radioisotopes that were released comprehensively after the accident of NPP and contaminating the surrounding areas. However, LBR for the incidence of leukemia is smaller in female than in male.

After the Chernobyl nuclear reactor accident, a large number of people survived from various types of diseases, of which women survived greatly from the breast and thyroid cancers. The occurrence of such diseases is due to the release of ^{131}I, ^{134}Cs, and ^{137}Cs radionuclides from the reactor,reported by UNSCEAR[76]. From the study conducted by Narendran et al. [47], it may berevealed that thewomen from radioactive contaminated areas developed thyroid cancer 2.5 times more than men. So, women those are living at such radioactive contaminated areas have a higher risk of developing the breast and thyroid cancers than men. Besides, women are suffered from other health problems such as changes in sex ratio, early mortality, Down's syndrome, and other genetic alterations.

In case of Jaduguda Uranium Mine, the local women of the mine area have been suffered from some healthproblems like miscarriages or still birth, unable to conceive baby, fatigue,weakness and depression due to the contaminations of the U-mine[72]. Thereare many other kinds of adverse health problems complaint by the local womenof the mine area similar to thehealth problemscaused by higher dose of radiation, e.g. birth defects, cancer, leukemia, and immediate death.From this reports, it may seems that the contaminated environment surrounding the mine areas can induce health effects acutely to the local people including women. The women of the Jaduguda U-mine areas have the high risks of occurrence of the infertility and congenital anomalies, child death, intra uterine deaths, premature birth, and spontaneous abortion, and most common health diseaseis leucorrhoea (3.4%)[73]. Regarding the deactivated uranium mine at Cunha Baixa[10], Lourenço et al.found the significant differences in total white blood cell (WBC) count in the blood samples of females of ages bellow 40 years, showing an increase in WBC in the females of the Cunha Baixa village. The same is observed by them for neutrophils in the same individuals. So, the result of the environmental contaminations due to U-mine can induce several health impacts on women population adversely.

In case of nuclear industry workers, the most common symptoms of female or women workers are infertility and increased risk of fetal loss[50].

The lifetime risk of lung cancer attributableto continuous life-long exposure to indoor ^{222}Rn isotope is found as higher for men than for women. But, the negative results are observed in another study[43], in where it ismentioned that a higher mortality rate found in female residents of high background natural radiation areas due to the higher indoor radon dose. So, the radiosensitivity of radionuclides to organs is differing between men and women.

From the study Pettersen et al.[31], it is revealed thatwomenin iodine-deficient regions of Sweden is associated with a 17% increased risk of the follicular cancer in women (relative risk

1.17).The study suggest that iodination of the food supply is not related tothe occurrence of thyroid cancer.

The committed effective doses due to intake of natural radionuclides through the consumption of some fishesarefound as high in female and low in male, whereas the doses due to intake of artificial radionuclides are approximately the same[35]. This suggests that the radiosensitivity of natural radionuclides to women is higher than men, when compared to artificial radionuclides.

Domingo has been mentionedthat the effect of the toxicity of the natural and depleted uranium results in the decreased fertility, embryo or fetal toxicity, and the reduced growth of offspring at different gestation periods of women[45]. Thus, uranium toxicity is not only acutely affects kidney and lungs[55], but it has also adverse effects on women during their gestation periods.

Salih et al. [36]observed that the level of the radon concentration urine is high than in blood of the female cancer patients, additionally, the radon in the samples of blood and urine of women of the exposed group is higher than those of the control group.

Salih and Jaafar observed that the concentration of alpha-emitters in the uterine tissues of the female cancer patients and women with fertility problems are vary from one woman to another, depending on their ages and the allergic reaction of uterus to the radiation, and also depending on the geological formation of the area[40].

The concentrations of some radionuclides deposited in human teeth are higher in female teeth than in male teeth[33]. On the other hand, the gross alpha and gross beta radioactivitiesof the female's teeth are quite low than those in the male's teeth samples[32, 39]. From this negative result, it can be realized that the concentrations of nuclides in human teeth depend on the geological formation of the region and the food habits of the local people.

The high level exposure to ionizing radiation on the pregnant women results in the possibility of growth restriction, spontaneous abortion, and mental retardation[20].Non-cancer health effects have not been detected on the pregnant women at any stage of gestation after exposure to ionizing radiation of less than $0.05\ Gy$.

Upton and co-workers found that $20-40$ numbers of females out of $100{,}000$ are died due to breast cancer[18] due to lifetime of cancer attributable to $0.1\ Sv$of whole-body radiation exposure.

From the above discussions, it is observed that the occurrence of the radioactivity-induced diseases in females is high than in males. The female's organs are highly sensitive to the radioactive radiation than the male's organs with few exceptions such as radon exposure.ICRP reported that the overall lethality risk to ionizing radiation for women is approximately 35% more than that for men[8]. The risk for radiation-induced breast cancer in men is negligible, but it is induced significantly in female. Thethyroid gland have a lethality risk about 6 times more than that for men and additionally

the breast risk being substantially greater[8]. It is seen that the risks of occurrence of the solid cancer, leukemia, thyroid and breast cancers can vary with gender.Gender-specific cancers and female breast cancer seem to be the main reason for the heightened risk for women[61].

The younger females have the higher risk to induceradiation-associated breast cancer, whereas the women of ages more than 50 years have no measurably increased risk of breast cancer due to the radiation exposure [80]. It may due to the fact that the breast tissue of adolescent females is more susceptible to induce carcinogenic effects by the exposure to ionizing radiation[63, 69]. Additionally, the breast tissue is a development tissue and it is present largely in young women than in men. On the other hand, the length of the time that tumor promoters (such as endogenous hormones) operate radiation exposure has an important influence on the increase of the radiation-induced breast cancer[77]. It is also observed that the occurrence of the risk of breast cancer can be enhanced with family history of breast cancer of a female person.

This study cannot find to fully understand the reason of the increased harmful effects on women's health due to the radioactive or other ionizing radiations. In various literatures, it was mentioned that the developing tissues such as brain, reproductive, breast, and fetus are more sensitive to ionizing radiations, noting the masses of reproductive tissue and breast tissue are present largely in the young women, therefore, the effective damages in these tissues may appear quickly than the other tissues by the exposures to same dose of radiation. The hormonal differences between women and men may have some impact on the enhanced radio sensitivity of women[81]. Other unknown influencing factors related to human biology may greatly present in females, and thereby some of these factors may also be assumed to be responsible for the incidence of some harmful effects comprehensively on females. In case of pregnant women, the changes in hormonal balance during pregnancy can possibly have some influencing effect on radiation sensitivityto the developing embryo or fetus[8].

As the health diseases such as genetic problems or cancers appear after some considerable time of the radiation exposure, therefore it is very difficult to differentiate from identical diseases with different sources. Therefore, sources of the health diseases must be determined to know whether these are due to radioactivity or not, if these are radioactivity-induced diseases, then it is very important to find the source and to take an initiate action for controlling or preventing the emitted radioactive radiations so that radioactivity-induced diseases cannot unintentionally appear in human population in their future life.

CONCLUSIONS

This study provide the important informationregardingthe occurrence of adverse health effects in females due to the effects of the nuclear disaster, nuclear industry, mining, natural and depleted uranium, contaminated environment and exposure to radon isotopes.

The female gender are vulnerable to the radioactive radiation and other ionizing radiation, especially the developing tissues of organs of the younger females are more sensitive to such radiations. Most of the females have a higher risk of radiation-induced diseases like cancers in thyroid and breast, solid cancer,multiple myeloma,and some other adverse health problems such as infertility, problems in reproductive systems, ovarian failure, heart diseases, child death, birth defects, and gene mutations. Younger females have the higher risk to induce radiation-associated breast cancer than the females of older ages.

Alpha-radiation emitted from the radon and uranium can aggravate the infertility, reduce the growth of offspring, and can significantly damaging the fetal or embryo and female reproductive systems. Thus, the association between the alpha radioactivity of blood and urine and the cancers may persist in the females with cancer problems.

However, the study cannot find to fully understand the reason of the increased harmful effects on women's health due to radioactive or other ionizing radiations. The developing tissues such as brain, reproductive, breast, and fetus are more sensitive to ionizing radiations, therefore, the effective damages in these tissues may appear quickly than the others by the exposures to same dose of radiation. The hormonal differences between women and men may have some impact on the enhanced radiosensitivityto women[81]. Other unknown influencing factors related to human biology may greatly present in females, and thereby some of these factors may also be assumed to be responsible for the occurrence of some radioactivity-induced harmful effects significantlyin females.

During the pregnancy, concerns must be focused in preventing the inadvertent radiation exposure on the developing tissues of the reproductive systems, fetuses and on the pregnant women. As the fetuses of embryos are sensitive to ionizing radiation, so the pregnant women who are living at the high background radiation area or any radioactive contaminating areas, they should be checked their radiation level routinely. They should also consult with theradiologist if they have any concern about radiation exposure to their fetuses. It is essential to protect from the incidence health risks of the prenatal after birth and also of the women themselves.

For the protection of our lives, the sourcesof the health diseases must be determined to know whether these are due to radioactivity or not, if these are radioactivity-induced diseases, then it is very important to find the source and to take an initiate action for controlling or preventing the

radioactive radiations so that radioactivity-induced diseases cannot unintentionally appear in human population in their future life.

Further, the systematic studies are necessary to elucidate the gender dependent radiosensitivity from fetus age to old age, and to ensure the people of different ages are equally protected from radioactivity.

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