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RADIOACTIVE FALLOUT FROM THE 2011 JAPAN NUCLEAR PLANT ACCIDENT AND SOME RECOMMENDED PRECAUTIONS AND COUNTERMEASURES

SUMMARY

Radioactive isotopes are naturally present in the environment including those found in our bodies, food and water. However, potentially large amounts of radioisotopes may be discharged into the environment as a result of nuclear power plant failures/accidents. Radioactive fallout results from either the explosion of a nuclear device or leakage from a nuclear reactor. In the past century, prior to the recent earthquake and tsunami in Japan, two serious nuclear accidents had occurred: the leakage at Three-Mile Island (USA) in 1979, and the devastating explosion and meltdown at Chernobyl (Ukraine) in 1986.

The recent event in Japan in March 2011 exposed the fragility of the food supply to radiation contamination due to a devastating earthquake (9.0 Richter scale) and subsequent tsunami where several nuclear reactors at the Fukushima Daiichi nuclear plants exploded due to the loss of power needed to cool both the fuel and spent fuel rods. This lack of control resulted in some of the fuel rods melting, thereby producing a number of nuclear by-products such as caesium-137 and iodine-131. An unpredictable amount of radioactive fallout was, and continues to be, produced for which the extent and time-frame remain unknown. Radioactive caesium-137 and iodine-131 are the most worrisome contaminants that may be distributed to many regions through atmospheric rain and wind. Flora, fauna, aquatic and land farms, domestic and wild animals, grasslands and rivers could be contaminated by these radionuclides. Iodine-131, which could escape into the atmosphere as a result of reactor malfunctions, is more volatile than caesium-137. I-131 is particularly harmful to the thyroids of young children resulting from inhalation of contaminated air or ingestion of contaminated food. Potassium iodide tablets taken orally or through the consumption of iodine-containing foods are possible remedies. Increasing one's immune system function by consuming more fruits and green, leafy vegetables that are high in antioxidants is also highly recommended. Ingestion of antioxidant-rich foods may also protect against oxidative damage produced by radiation.

<u>This Scientific Information Bulletin is NOT about the safe preservation of food by controlled irradiation in accordance with regulatory requirements.</u>

<u>Rather, it is about the potential, accidental contamination of people, air, water, crops or animals by uncontrolled amounts and types of radioactive materials arising from nuclear reactor accidents.</u>

BACKGROUND

Radioactive elements in food and the environment

Radioactive isotopes of elements (radionuclides) are naturally present in the environment including those found in our bodies, food and water. Radiation also comes from space (cosmic rays) as well as from naturally-occurring radionuclides found in soil, water and air (WHO-FAO, 2011). People can be exposed to radiation from man-made activities including medical diagnostic interventions. Radioactivity can also contaminate food after it has been discharged into the environment from industries that concentrate natural radionuclides as well as those from civil or military nuclear operations (WHO- FAO, 2011). Background levels of radionuclides in foods vary and are dependent on several factors including the type of food and the geographic region where the food has been produced. In general, potassium-40 (K-40) is the most commonly occurring natural radioisotope. For example, levels of K-40 in milk are around 50 Bq/L, and those for meat, bananas and other potassium rich products, levels may be several hundred Bq/kg. Other natural radioisotopes exist in much lower concentrations and originate from the decay of uranium and thorium (WHO-FAO, 2011).

When high levels of radioisotopes are discharged into the environment items such as fruits and vegetables, seafood, and animal feed may become contaminated through contaminated rainwater or snow (WHO-FAO, 2011) and may be subsequently consumed by animals and/or humans. Radioactivity in water can also accumulate in rivers and sea, thereby affecting fish and seafood. Of immediate concern is iodine-131 which can be distributed over a wide area through water and crops. For example, milk may become rapidly contaminated as a result of cows consuming contaminated feed. Administration of stable iodine to milk can reduce transfer of radioiodine such that reduction values ranging from 1.1 to 2.2 have been determined (Vandecasteele et al., 2000). Other studies have also observed that oral administration of stable iodine as a potentially useful countermeasure to reduce radioiodine in milk achieves up to three-fold reductions via transfer of iodine to the mammary glands, an active process which is satiable at high iodine plasma concentrations (Howard et al., 1996).

Iodine-131 has a relatively short half-life and will decay within a few weeks. In contrast, radioactive caesium, which can also be detected early on, has a longer half-life (Cs-134 half-life is about 2 years and that for Cs-137 is about 30 years) and can remain in the environment for an extended time (WHO-FAO, 2011). Radioactive caesium is also relatively easily transferred from feed to milk (WHO-FAO, 2011) and is deposited directly onto vegetal surfaces shortly after an accident, leading to potential consumption by animals (Howard et al., 2001).

According to the International Atomic Energy Agency (IAEA) (2009), human radiation exposure due to all natural sources amounts to about 2.4 mSv a year and this amount can vary depending on geographic location. The amount of ingested doses through food consumption is about 0.25-0.4 mSv per year (IAEA, 1989).

The main human health concern due to high radiation exposure over the long term is the possibility of developing cancer. The degree of harm depends on the type of radionuclides and the length of exposure. Cancer types and target organs depend on the radionuclides. Many different kinds of radionuclides can be discharged following a major nuclear emergency; some are very short-lived (e.g., iodine; I-131, fluorine; F-20, zinc; Zn-71) while others are not readily transferred to food (e.g., xenon; Xe-133). Radionuclides generated in nuclear installations which could be significant for the food chain include: radioactive hydrogen (H-3), carbon (C-14), technetium (Tc-99), sulfur (S-35), iodine (I-131), uranium (U-235), plutonium (P-238u, P-239u, P-240u), caesium (C-134s and Cs-137) and others. An adult eating 200 g of spinach contaminated with 1000Bq/kg of Cs-137 results in 0.0026 mSv additional exposure. A one year old child consuming 500 mL milk contaminated with 100 Bq/L of I-131 results in 0.009 mSv additional exposure (WHO-FAO, 2011).

Radioactive iodine (I-131) is rapidly transferred to milk from contaminated feed where it can accumulate in the thyroid gland. Iodine which is inhaled or swallowed will also concentrate in the thyroid gland. Both scenarios increase the risk of thyroid cancer. Potassium Iodide (KI) supplements can be taken to prevent radioactive iodine from accumulating in the thyroid. Iodized salt is not recommended as an alternative to KI as the level of iodine is insufficient to saturate the thyroid (WHO-FAO, 2011).

Radioactive caesium, if consumed, is transferred uniformly throughout the body's soft tissues, thereby increasing the risk of cancer. However, compared to other radionuclides, caesium-137 remains in the body for a relatively short time (WHO-FAO, 2011). Over 80% of ingested plant-associated radiocaesium is absorbed from the ruminant gut and is subsequently transported to all soft tissues, milk, urine and feces (Mayes et al., 1996).

Caesium-137 – a serious fallout contaminant

When the Fukushima Daiichi power plant reactors exploded and fuel rods became overheated, fission reactions continued and produced a number of products including caesium-137 which constitutes the greatest risk to health. Caesium 137, together with Caesium-134, iodine-131, and strontium-90 were, and continue to be, released into the environment as a result of the reactor explosions. The concentrations of this fallout have not yet been determined. Cs-137 has a half-life of about 30 years and decays by beta emission to metastable nuclear isomers of barium-137 and barium-137m.

The mixtures of radioactive fission products in a power reactor accident can be divided into two groups – those that are more volatile and those that are less volatile. A greater proportion of xenon and iodine are found in the volatile group while caesium and plutonium are less volatile. In the Chernobyl accident, however, a high levels of caesium isotopes were released and dispersed by wind over a wide area (Russia, Ukraine, Belarus and most parts of Europe except the Iberia region). For example, the mean contamination of caesium-137 in Germany was 2000-4000 Bq/m^2. This corresponds to a contamination of 1 mg/km^2 of caesium-137 totaling about 500 grams deposited over all of Germany. In the case of the Fukushima accident, depending on the direction of the wind, neighbouring countries west of Japan such as Korea, China (including Hong Kong and Macau), Vietnam, Laos, Cambodia, Thailand, Malaysia, Singapore, and

Indonesia could be contaminated. With an eastward wind, some Pacific islands including the Hawaii island chain and the continental United States would be affected.

At the time of this bulletin it is difficult to predict how large a quantity of caesium-137 was released from the Fukushima power plant. Reports in March and April, 2011 indicated a large quantity of water was either dropped by helicopters or pumped into those reactor pools suggesting that some caesium would react with water and form caesium hydroxide which would dissolve in water. If this water is contained inside the reactor buildings then leakage of caesium to the environment would be minimal.

Health risk of radioactive caesium

Exposure to radionuclides can result in their concentration in some tissues of the body which is dependent on the element. These elements will go through gamma, beta, and alpha decays, thereby causing internal damage.

The biological behaviour of caesium is similar to potassium. After entering the body, caesium is distributed somewhat uniformly throughout the body with higher concentrations in muscle tissues and lower concentrations in bones. The *biological* half-life of caesium is rather short at about 110 days. As indicated above, soil, water, vegetation, aquatic life and air contaminated with caesium-137 can affect animals and/or humans through their consumption/inhalation.

Countermeasures to minimize Caesium-137 contamination

Addition of fish or other products rich in Ca or F (e.g. CaCo3 enriched flour or bonemeal) to test animal diets decreases accumulation of 90Sr, with maximum effects achieved by administration of fish mass and calcium carbonate to provide a dietary level of Ca slightly above the physiological norm. Addition of Laminaria (seaweeds) and fish mass to the diet is likewise effective in reducing accumulation of 137Cs, and enrichment of diets with these was expected to help minimize accumulation of 90Sr and 137Cs in populations living in areas affected by the Chernobyl nuclear accident (Shandela, 1993).

After the Chernobyl reactor accident, fallout and 'washout', contamination of air, soil, plants and animals by Cs-134 and Cs-137 occurred. Regional differences were also noticed. The transfer and distribution of Cs-137 in edible parts of game animals as well as Cs-134 and Cs-137 in edible fungi from the Bavarian National Park which may be eaten by the animals was of concern. Thus, suitable hunting practices, (meat inspection and food legislation were required (Kreuzer and Hecht, 1988).

Ingestion of caesium-137 can be treated with Prussian blue (iron potassium cyanide) which chemically binds, then expedites its expulsion from the body (Fact Sheet, US Centers for Disease Control).

Caesium can be eliminated from the body by consuming potassium-salt fluids such as some of the sports drinks or diluted seawater.

General treatments when a person has ingested radioactive contaminants:

1) PABA (para-amino benzoic acid), a B vitamin, can be given orally in 2-gram dose (up to about 5 grams), five times a day, and combined. This treatment helps the body's DNA repair mechanisms. It is also suggested that a reasonable B-complex be used. Continue for 3-6 months.

2) Calendula oil is used in cancer treatment to prevent and heal radiation burn. It is recommended that 2 mL be taken several times per day for 2-3 months.

3) Hyperbaric oxygen treatment boosts the immune system after radiation, reducing apoptosis and preserving leukocytes. Twenty to thirty treatments are recommended.

(Hunt, 2011).

Iodine-131 – the fallout of the greatest concern

I-131 is an important isotope of iodine and is a major product from uranium, plutonium, and indirectly from thorium fission, comprising nearly 3% of the total products of fission (by weight). It is a major radioactive hazard in nuclear fission products, and was a significant contributor to the health effects from open-air atomic bomb testing in the 1950s, from the Chernobyl disaster, as well as being a threatening presence in the recent Japanese nuclear crisis.

I-131 has a radioactive decay half-life of eight days. Due to its mode of beta decay (90% beta, 10% gamma), iodine-131 results in mutation and cell death through its ability to penetrate between 0.6 to 2 mm. Small incidental doses of iodine-131 are considered to be the major cause of increased thyroid cancers after accidental nuclear contamination. These cancers result from residual tissue radiation damage and usually appear years after exposure, long after the I-131 has decayed.

Effects of Exposure to Iodine-131

Non-radioactive iodine in foods is absorbed by the body and preferentially concentrated in the thyroid where it aids in its functioning. The primary risk from exposure to high levels of I-131 is the occurrence of radiogenic thyroid cancer in later life, with children being more susceptible than adults. The risk can be minimized by taking iodine supplements, thereby raising the total amount of iodine in the body, reducing the uptake and retention in tissues, and lowering the relative proportion of radioactive iodine as compared to non-radioactive iodine. The most common method of treatment is to give potassium iodide to those at risk (WHO-FAO, 2011). The dosage for adults is 130 mg potassium iodide per day, about 700 times bigger than the nutritional dose of iodide (0.15 mg).

Following the Chernobyl nuclear power plant disaster, iodine supplements were not distributed to the population living nearest to the plant whereas they were widely distributed to children in Poland. Within the USA, the highest I-131 fallout doses occurred during the 1950s and early 1960s to children who consumed fresh milk contaminated as the result of above ground testing of nuclear weapons in the Nevada desert.

The nuclear accident of March 2011 in Fukushima, Japan resulted in significantly elevated I-131 levels in foodstuffs from spinach to tap water both near the plant and as far away as Tokyo. A peak of 190 Bq/L was recorded in a Tokyo water purification facility.

Finally, I-131 is eliminated from the body through its radioactive decay, and small amounts may also be eliminated through sweat and urination. As a precaution to prevent cross contamination to other family members, especially children, it is advisable to regularly clean toilets and sinks, and change bed sheets and clothing used by the person who received the treatment, using commercially available radioactive decontaminants. (McMaster University Medical Centre). Use of general purpose decontamination products is not recommended because they may spread or volatilize it (Purdue University Biosafety Manual, 2002).

The Wisdom and Timing of Taking Potassium Iodide

The consumption of potassium iodide (KI) supplements, called "thyroid blockers," is said to be the "go-to" emergency treatment, according to Kalsa Soram, professor of clinical medicine at Cedars-Sinai Medical Centre in Los Angeles, California, USA and Richard T. Kloos, Chief Operating Officer of the American Thyroid Association (ATA). The United States government states that taking an iodide supplement provides protection for about one day per dose (U.S. FDA, 2001).

The decision to take a potassium iodide supplement should be guided by advice given by local officials, thereby preventing one from overloading the body with an unnecessary amount of iodide.

A low-cost alternative to commercially available iodine pills is to prepare a saturated solution of potassium iodide. Reagent grade crystals KI is preferred over 'pharmacologic grade' which can be stored for a long period of time. The adult protective dose of 130 mg mentioned above is equal to four drops of saturated KI solution and two drops (65 mg) is suitable for an infant. Due to the bad taste of the solution, it is recommended that it be administered in a ball of bread. If an individual is allergic to iodine, sodium perchlorate is an alternative (WHO, 1999)

KI supplement is only necessary for those contaminated within a 160-km (100 miles) radius of the meltdown zone.

Alternatives to Taking Iodide Tablets

For those distant from a nuclear disaster zone, an alternative way to protect one's self is to consume foods rich in natural iodine and antioxidants (Prasad, 2005).

The best food sources of iodine come from the oceans including seaweed and other sea vegetables (but not sourced from a nuclear disaster zone).

The Japanese are the biggest seaweed eaters in the world. It is, therefore possible that their bodies have an adequate storage of iodine, and are thus protected from the fallout of radioactive iodine-131.

The most popular types of seaweeds are:

Kelp – contains 12 mg of iodine per teaspoon of granules. Kelp reduces intestinal absorption of radioactive strontium-90 by 50-80%. (Skoryna et al., 1964)

Kombu – is another variety of kelp that comes in strips. It contains iodine that is not affected by heat during cooking.
Dulse and wakame are also good sources of iodine.

Other foods rich in iodine include: asparagus, garlic, lima beans, mushrooms, sesame seeds, soybeans, spinach, summer squash, Swiss chard, and turnip greens.

In addition, miso made from soybeans is a good source of iodine which is frequently used as a soup base in Japan. Soybeans provide ample iodine on their own, but studies have shown that miso increases resistance to radiation by a factor of five (Ohara et al., 2001)

Radioprotection by food supplements and nutrients

Exposure of an organism to ionizing radiation results in a variety of genetic damage that is generally attributed to free radical interactions resulting in possible DNA and other cellular macromolecular damage. Ingestion of antioxidant vitamins can protect against such oxidative damage (Konopacka et al., 1998) by significantly reducing the chromosomal damage in the cells exposed to radiation (Sharma and Kesavan, 1993). Administration of antioxidants such as vitamin C, E, β-carotene, chlorogenic acid or metalloelements can exert a protective effect against *in vivo* genetic damage induced by exposure to radiation.

Vitamin C is a water soluble antioxidant which could act as a first defense against radicals formed after radiation can also protect against DNA and lipid damage (Konopacka et al., 1998). Ingestion of vitamin C can reduce the amount of chromosomal damage and the antimutagenic protection is observed at low dose (50-100 mg/kg/day). Foods rich in vitamin C include: papaya, kale, red bell peppers, broccoli, strawberries, and kiwis etc. High concentrations of vitamin C (400 mg/kg/day) can, however, potentiate the production of hydroxyl radicals from hydrogen peroxide via the Fenton reaction which enhances the level of radiation-induced damage (Morales-Ramirez et al., 1998).

Vitamin E is a particularly active lipid-soluble antioxidant and its major function is attributed to protection of the cellular membrane from oxidative damage by free radicals. Foods rich in vitamin E include: sunflower seeds, almonds, olives and spinach, and selenium-rich foods include Brazil nuts, salmon, shrimp, turkey and brown rice. An *in vivo* study showed that ingestion of 100 IU/kg of vitamin E resulted in a strong protective effect against mortality rate in mice treated with a radiation dose of 9 Gy, and that vitamin E acted synergistically with selenium (4 mg/kg) (Chow, 1988). Selenium's protective effect occurs by inducing or activating cellular free-radical scavenging systems and by enhancing peroxide breakdown. Selenium also plays a role in the transport and storage of vitamin E which itself is a free-radical scavenger that can prevent the propagation of peroxidation processes thereby protecting against lipid oxidation of the cellular membrane (Borek et al., 1986).

A low dose of vitamin C (50-100 mg/kg/day) combined with vitamin E and β-carotene at a high doses (200 and 12 mg/kg/day, respectively) results in synergistic action since vitamin C can regenerate vitamin E via the reduction of the alpha-chromanoxyl radical. This combination of vitamins produces the most effective treatment against chromosomal damage resulting from free radical production and increases the rate of DNA repair (Konopacka et al., 1998).

Ingestion of vitamin E in combination with vitamin C, or curcumin in combination with vitamin C and chlorogenic acid, can reduce the frequency of radiation-induced genetic damage by 38%. Carrots, spinach, cabbage, guava and lemon are rich sources of vitamin C and β-carotene, almonds and peanuts contain large amounts of vitamin E, chlorogenic acid is present in large amounts in coffee, and curcumin is the main colouring compound of turmeric. Ingestion of foods containing large amounts of natural antioxidants can reduce the chromosomal damage induced by exposure to radiation (Sharma et al., 1994).

Metalloelements such as copper, iron, manganese and zinc, which cannot be synthesized *in vivo*, are essential and are required by all cells for normal metabolic processes. Copper complexes have radiation protection and radiation recovery activities, and cause rapid recovery of immunocompetence and radiation-induced damage to cells and tissues. Iron, manganese and zinc complexes have also been found to prevent death in lethally-irradiated mice. These pharmacological effects result from these essential metalloelement-dependent enzymes, preventing the accumulation of pathological concentrations of oxygen radicals due to radiation-induced bond hemolysis (Sorenson, 1992).

Radioprotection by food components and phytochemicals

Besides the more common antioxidants, phytochemicals have also been reported to be radioprotective in various model systems. These include green tea, spices like holy basil and curcumin, berries, apple and plum (polyphenols), Chinese herbal medicines, cruciferous vegetables (e.g., cabbage, broccoli), Panax ginseng, Shigoka extract, Ginko biloba, garlic, Shigoka extract, milk thistle (silymarin), curcumin, algal powder, pectin preparation and lycopene. These compounds can provide significant protection against chromosome aberrations and lethality during radiation exposure (Uma Devi et al., 1999).

After the Chernobyl accident, pure β-carotene or β-carotene rich Dunaliella algae was given to children. β-carotene rich Dunaliella algae resulted in better radioprotection than pure β-carotene. It is possible that the β-carotene present in the algae can act in synergy with other constituents of the plant nutrients (Ben-Amotz et al., 1998). Apple pectin preparation containing vitamins and mineral nutrients (Vitabect) was also given to children in Chernobyl as pectin can chemically bind cations like caesium in the gastrointestinal tract thereby increasing faecal excretion (Hill et al., 2007). The Cs-137 body burden of highly contaminated children was significantly reduced 2-fold in children treated with Vitabect.

Finally, melatonin (300 mg) appears to reduce *in vitro* incidence of chromosomal aberrations and micronuclei produced by radiation treatments, and protect against DNA damage (Vijayalaxmi et al., 1998). Melatonin scavenges hydroxyl and peroxyl radicals as well as peroxynitrite anions, and appears to be more effective than vitamin E as an antioxidant (Pieri et al., 1994). Thus, daily ingestion of melatonin should be considered.

CONCLUSION

When large amounts of radioisotopes are discharged into the environment due to accidents such as a nuclear power plant explosion, they can affect foods, rivers, seas, rainwater and snow. Therefore, the consumption of iodide tablets when recommended, and the ingestion of foods rich in iodine and various antioxidants, phytochemicals and metalloelements, can protect against oxidative damage produced by radiation.

References

Ben-Amotz, A., Yatziv, S., Sela, M., Greenberg, S., Rachmilevich, B., Shwarzman, M., Weshler, Z. 1998 effect of natural β-carotene supplementation in children exposed to radiation from the Chernobyl accident. Radiat. Environ.Biophys. 37, 187-193.
http://www.ncbi.nlm.nih.gov/pubmed/9840488

Borek, C., Augustinus, O., Mason, H., Donahue, L., Biaglow, JE. 1986 Selenium and vitamin E inhibit radiogenic and chemically induced transformation in vitro via different mechanisms. Proc. Natl. Acad. Sci. 83, 1490-1494.

Chow, CK 1988 Interrelationships of cellular antioxidant defense systems. In Cellular antioxidant defense mechanisms, vol.II, Chow CK. Ed., CRC Press Boca Raton, 217-237.

Hill, P., Schläger, M., Vogel, V., Hille, R., Nesterenko, AV., Nesterenko, VB. 2007 Studies on the current 137Cs body burden of children in Belarus-can the dose be further reduced? Rad. Prot. Dos. 125, 1-4, 523-526.

Howard, BJ., Beresford NA., Voigt G. 2001 Countermeasures for animals products: a review of effectiveness and potential usefulness after an accident. J. Environm. Radioact. 56, 115-137.
http://www.pathobiologics.org/btac/ref/JEnvironRadioact_56_115-137_2001.pdf

Howard B.J., Voigt, G., Segal, M., Ward, G. 1996 A review of countermeasures to reduce radioiodine in milk of dairy animals. Health Physics, 71, 661-673.
http://www.mendeley.com/research/review-countermeasures-reduce-radioiodine-milk-dairy-animals/

Hunt, E (2011). Comments in “Fallout at Fukushima”, The Scientist, 22 March 2011. http://www.the-scientist.com/news/display/58085/#comments

IAEA 2009 Quantification of radionuclide transfer in terrestrial and freshwater environments for radiological assessments (IAEA TECDOC Series No.1616)
http://www-pub.iaea.org/MTCD/publications/PDF/te_1616_web.pdf

IAEA, 1989 Measurement of radionuclides in food and the environment A guidebook, Technical reports Series No. 295.
http://www.mendeley.com/research/review-countermeasures-reduce-radioiodine-milk-dairy-animals/

Konopacka, M., Widel, M., Rzeszowska-Wolny, J. 1998 Modifying effect of vitamin C, E and beta-carotene against gamma-ray-induced DNA damage in mouse cells. Mut. Res. 85-94.
http://www.ncbi.nlm.nih.gov/pubmed/9733928

Kreuzer, W and Hecht, H (1988) Radioactivity in Bavarian game animals following the Chernobyl reactor accident, Archiv fuer Lebensmittelhygiene: 39 (2) 35-40, (3) 73-77
Mayes RW., Beresford, NA., Howard, BJ., Vandecasteele, CM., Stakelum G. 1996 The use of the true absorption coefficient as a measure of the bioavailability of radiocaesium in ruminants. Rad. Environ. Biophys. 35, 101-109.
http://www.ncbi.nlm.nih.gov/pubmed/8792457

McMaster University Medical Centre. Precautions after Out-patient
Radioactive Iodine (I-131) Therapy
http://www.hamiltonhealthsciences.ca/documents/Patient%20Education/I131RadioactiveIodineTherapyHHS-trh.pdf

Morales-Ramirez, P., Mendiola-cruz, MT., Cruz-Vallejo, V. 1998 Effect of vitamin C or β-carotene on SCE induction by gamma rays in radiosensitized murine bone marrow cells in vivo. Mutagen. 13, 139-144.
http://www.ncbi.nlm.nih.gov/pubmed/9568585

Ohara M, Lu H, Shiraki K, Ishimura Y, Uesaka T, Katoh O, Watanabe H. 2001. Radioprotective effects of miso (fermented soy bean paste) against radiation in B6C3F1 mice: increased small intestinal crypt survival, crypt lengths and prolongation of average time to death. Hiroshima J Med Sci. 2001 Dec;50(4):83-6.
http://www.ncbi.nlm.nih.gov/pubmed/11833659

Pieri, C., Marra, M., Moroni, F., Recchioni, R., Marcheselli, F. 1994 Melatonin : a peroxyl radical scavenger more effective than vitamin E. Life Sc. 55, PL 271-276.
http://www.ncbi.nlm.nih.gov/pubmed/7934611

(Prasad, KN (2005). Rationale for using multiple antioxidants in protecting humans against low doses of ionizing radiation,___**British Journal of Radiology, 78:** 485-492 http://bjr.birjournals.org/cgi/content/full/78/930/485) .

Purdue University Biosafety Manual (2002), page 7.http://www.ehs.iupui.edu/biohaz_manual/biosafety_manual_v0502.pdf .

Sarma L., Kesavan, PC. (1993) Protective effect of vitamin C and E against gamma-ray-induced chromosomal damage in mouse. Int. J. radiat. Biol. 63, 759-764.
http://www.ncbi.nlm.nih.gov/pubmed/8100263

Shandala, NK (1993) Alimentary means of decreasing radiation caused by Cs and Sr radionuclides, Gigienai Sanitariya: 10, 51-54

Sharma, L., Suresh, K., Abraham, K., Kesavan, PC. 1994 Chromosomal damage by low doses of radiation: protection by combinations of dietary antioxidants. Current Sc. 66, 11, 861-862.

Skoryna S C et al. (June 1964). Studies on Inhibition of Intestinal Absorption of Radioactive Strontium, Canad. Med Assoc J.
http://www.livestrong.com/article/354597-the-health-benefits-side-effects-of-kelp/
http://www.appliedhealth.com/index.php?option=com_content&view=article&id=108373

Sorenson, JRJ. 1992 Essential metalloelement metabolism and radiation protection and recovery. Rad. Res. 132, 19-29.
http://www.ncbi.nlm.nih.gov/pubmed/1410271

Uma Devi, P., Ganasoundari, A., Rao, BSS., Srivinvasan, KK. 1999 In vivo radioprotection by Ocimum flavonoids: survival of mice. Radiat. Res. 151, 74-78.
http://www.ncbi.nlm.nih.gov/pubmed/9973087

U.S. Food and Drug Administration, Center for Drug Evaluation and Research (CDER) Guidance (2001) Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies, http://www.fda.gov/cder/guidance/index.htm

Vandecasteele, CM., Van Hees, m., Hardeman, F., Voigt, GM., Howard BJ. 2000 The true absorption of iodine and effect of increasing stable iodine in the diet. J. Environ. Radioact. 47, 301-317.
http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VB2-3XR2V43-7&_user=10&_coverDate=02%2F29%2F2000&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1738798456&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=039c241b4c1273922ab4e0234b608c18&searchtype=a

Vijayalaxmi, V., Reiter, RJ., Meltz, ML., herman, TS. Antioxidative Effects of Melatonin in Protection Against Cellular Damage Caused by Ionizing Radiation, Proceedings of the Society for Experimental Biology and Medicine 2000;225:9-22.
http://ebm.rsmjournals.com/cgi/content/full/225/1/9

WHO,1999. Guidelines for Iodine Prophylaxis following Nuclear Accidents (World Health Organization, http://www.who.int/ionizing_radiation/pub_meet/Iodine_Prophylaxis_guide.pdf .

WHO-FAO 2011 International Food Safety Authorities Network (INFOSAN) Information on Nuclear Accidents and Radioactive Contamination of Foods, March 30 pp.1-5.
http://www.who.int/foodsafety/fs_management/INFOSAN_note_Radionuclides_and_food_300311.pdf

Further Reading

Fallout Foods That Block Radiation.
http://myhealingkitchen.com/featured-articles/fallout-foods-that-block-radioactivity/

Fears over radioactive contamination cool Japanese food market in China
http://news.xinhuanet.com/english2010/china/2011-04/11/c_13823851.htm

Indian Government Statement, 5 April 2011.
www.ndtv.com/article/india/india-bans-food-imports-from-japan-over-radiation-fears-press-statement-96618

FSANZ Statement “Safety of food from Japan”
www.foodstandards.gov.au/scienceandeducation/factsheets/factsheets2011/safetyoffoodfromjapa5110.cfm

The Scientist, 22 March 2011. "Fallout at Fukushima"
www.the-scientist.com/news/display/550885

UK Food Standards Agency. 19 April 2011. "Radioactivity in food: your questions answered"
http://www.food.gov.uk/safereating/rad_in_food/radioactivity/

US Environment Protection Agency. "Radiation Doses in Perspective"
www.epa.gov/radiation/understand/perspective.html

US Environment Protection Agency. "Japanese Nuclear Emergency: Radiation Monitoring: Frequently asked Questions"
www.epa.gov/radiation/japan-faqs.html

US Environment Protection Agency. Statement 21 April 2011. "Japanese Nuclear Emergency: EPA's Radiation Monitoring"
www.epa.gov/radiation/

Wiebe, C. Medscape, 13 March 2011. "Iodine Pills: What to Tell Patients"
www.medscape.com/viewarticle/739180?src=mp&span=17

World Health Organisation (WHO), Statement 8 April 2011. "FAQs: Japan nuclear concerns"
www.who.int/hac/crises/jpn/faqs/en/index.html

Wikipedia Article on Iodine-131
http://en.wikipedia.org/wiki/Iodine_131

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