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Query: Records containing the term strontium radioactive

1
NAME: STRONTIUM, RADIOACTIVE

HSN: 7403

RN: NO CAS RN

NOTE:

This record contains information on the radiological aspects of strontium and its compounds. For information on the general toxicity and environmental fate of strontium ions and strontium compounds, refer to the STRONTIUM COMPOUNDS record. For general toxicological, safety and handling, and environmental information on ionizing radiation emitted from chemical sources including strontium, refer to the IONIZING RADIATION record.

This record does not address regulatory or licensing requirements that may be imposed by state, local or federal authorities.

HUMAN HEALTH EFFECTS:

TOXICITY SUMMARY:

The beta-particle emitters strontium-90, yttrium-90 and 32-P-phosphate ... are bone-seeking radionuclides that attach to bone surfaces, from which they irradiate the marrow, and the depth of penetration of the radiation often exceeds that of similarly located alpha-particle emitters. Beta emissions from strontium-90 have a limited ability to penetrate through tissue. For that reason, radiostrontium must be internalized or placed in close contact with skin before adverse health effects will occur. The "bone-seeking" behavior of strontium is the basis for concern regarding oral or inhalation exposures to the radioactive isotopes, particularly strontium-90, with its long half-life of 29 years and highly energetic 0.546 MeV beta particles, plus the 2.2 MeV beta particles of its short-lived yttrium-90 decay product isotope. /Srontium-90, yttrium-90 and 32-P-phosphate/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 399, 477 (2001)] **PEER REVIEWED**

EVIDENCE FOR CARCINOGENICITY:

There is inadequate evidence in humans for the carcinogenicity of strontium-90. /Strontium-90/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 478 (2001)] **PEER REVIEWED**

There is sufficient evidence in experimental animals for the carcinogenicity of pure beta-particle emitters (hydrogen-3, phosphorus-32, strontium-90, yttrium-90, yttrium-91 and promethium-147). /Tritium, phosphorus-32, strontium-90, yttrium-91, promethium-147/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at:

http://monographs.iarc.fr/index.php, p. V78 478 (2001)] **PEER REVIEWED**

HUMAN TOXICITY EXCERPTS:

/EPIDEMIOLOGY STUDIES/ More than 25,000 residents were exposed to external gamma radiation as well as internally from fission products (primarily from cesium-137, strontium-90, ruthinium-106, and zirconium-95) released into the Techa river from the nearby Mayak plutonium production facility, predominately in the early 1950s. Studies have been conducted of cancer mortality in residents and their offspring, as well as pregnancy outcomes. Initial dose estimates were based on average doses reconstructed for settlements. Efforts are ongoing to estimate individual doses for members of this resident cohort. To date, there is no evidence of a decrease in birth rate or fertility in the exposed population and no increased incidence of spontaneous abortions or stillbirths. There is some evidence of a statistically significant increase in total cancer mortality. Current estimates of the excess absolute risk (EAR) of leukemia in this cohort is 0.85 per 10,000 person-year Gy (95% confidence interval 0.2, 1.5), and for solid tumors the relative risk estimate is 0.65 per Gy (95% confidence interval -0.3, 1.0). Median dose estimates for soft tissue in this cohort are 7 mSv (maximum 456 mSv), and for bone marrow are 253 mSv (maximum 2021 mSv). Estimates of the relative risk for cancer of the esophagus, stomach and lung are similar to those reported for atomic bomb survivors. There is no evidence of an increase in cancer mortality in the offspring of exposed residents. There has also been one study of persons living in the town of Ozyorsk exposed to fallout from the nearby Mayak nuclear facility. An excess of thyroid cancer, 3-4 times expected relative to rates for all of Russia, has been observed. The excess is somewhat lower (1.5-2-fold higher) based on a comparison with Chelyabinsk Oblast rates. No estimates of radiation dose were included in this study. /Cesium-137, strontium-90, ruthinium-106, and zirconium-95 fission products/[NAS/BRER; Health Risks from Exposure to Low Levels of Ionizing Radiation BEIR VII-Phase 2. p. 380 (2005)] **PEER REVIEWED**

/EPIDEMIOLOGY STUDIES/ Perinatal mortality rates in the regions of Ukraine and Belarus surrounding the Chernobyl site increased in 1987, the year following the Chernobyl accident. The same year, increases of perinatal mortality were also observed in Germany and Poland, and the effect can be associated with the cesium burden in pregnant women. After 1989, there is an unexpected second rise of perinatal mortality in Belarus and Ukraine. This increase is shown to correlate with the strontium content in pregnant women. The findings parallel an increase of perinatal mortality in Germany following the atmospheric bomb tests in the 1950's and 1960's. While the effect from cesium is essentially limited to 1987, the effect from strontium persists until the end of the study period in 1998. The cumulative effect from strontium around Chernobyl outweighs the effect from cesium by at least a factor of 10. This is contrary to the assertion that the cesium content in the Chernobyl fallout was more than 10-times greater than the strontium content. Thus, the dose factor presently used seems to severely underestimate the effect of strontium on perinatal mortality. /Cesium and strontium fallout/[Korblein A; Radiats Biol Radioecol 43 (2): 197-202 (2003)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12754809" target=new>PubMed Abstract

/EPIDEMIOLOGY STUDIES/ In the Techa River population that was exposed to radiostrontium and radiocesium in drinking water and food between 1949 and 1956, an increase in the number of deaths from leukemia and solid cancers was reported. In the exposed group, the standardized mortality rate was 140 (95% CI: 131-150) per 100,000 compared to 105 (95% CI: 101-109) per 100,000 in the control group during the followup period (1950-1982). Absorbed doses to the red bone marrow in the study group were between 17.6 and 164 rad (0.176 and 1.64 Gy). No increase in cancer mortality was observed among offspring of exposed individuals. /Radiostrontium and radiocesium/[DHHS/ATSDR Toxicological Profile for Strontium p 77 (2004)] **PEER REVIEWED**

/EPIDEMIOLOGY STUDIES/ Epidemiological studies have found little or no association between oral exposure to radioactive strontium from fallout and cancer effects in humans. In an epidemiological study using the Danish cancer registry, no association was found between the incidence of thyroid cancer in Denmark between 1943 and 1988 and the levels of skeletal incorporation of 90-Sr from fallout. In another epidemiological study, data collected between 1959 and 1970 in a strontium-90 monitoring program in Glasgow, Scotland, were used to identify three cohorts with respect to the hypothetical risk for leukemia and non- Hodgkin's lymphoma, acute myeloid leukemia, all childhood cancers combined, and bone tumors. The three cohorts were a high risk group born in 1963-1966 (exposed to high levels of fallout, i.e., strontium-90, at a young age), a medium risk group born in 1959-1962 (exposed to high levels at an older age), and a low risk group born after 1966. Cumulative incidences for all cancers, leukemia and non-Hodgkin's lymphoma, and acute myeloid leukemia all showed a secular (progressive, noncyclical) increasing trend for children born before 1982. However, the study found no evidence for increased risks of total cancers, leukemia and Non-Hodgkin's lymphoma, or acute myeloid leukemia for cohorts born during the period of highest fallout (radiostrontium) exposure. The few cases of bone tumors showed a statistically nonsignificant increase for children born during the 'high risk' period. In contrast, the Techa River population that was exposed to contaminated water and food as a result of releases from a nuclear weapons facility exhibited a significant increase in the incidence of leukemia. /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 97 (2004)] **PEER REVIEWED**

/BIOMONITORING/ The results of a follow up of a group of fifty-two persons carrying body burdens of strontium-90 and radium-226 for a period of about 2500 days are given. The body burdens vary in the group from less than 10 per cent of the maximum permissible to somewhat more than 100 per cent of the maximum permissible burden. ... The large fluctuation in the strontium-90 excretion observed from day to day and at different times of the day could be greatly diminished by relating it to calcium excretion. No significant clinical changes could be observed in the exposed group except the signs of radiation dermatitis in some cases. A small but statistically significant increase in the number of red cells, hemoglobin and hematocrit values could be detected, when comparing the whole group to a group of healthy prospective blood donors. There was, however, no significant difference in these indicators when comparing persons with different levels of body burdens within the group. Karyological investigation of bone marrow cells showed a statistically significant increase in the occurrence of aneuploid cells as compared to healthy controls. Differences in the occurrence of aneuploid cells found in groups with different levels of body burden are at this stage of the study not statistically significant. A significant increase in the rate of chromosomal aberrations could be demonstrated in cases with cumulative body burdens higher than 10 per cent of the maximum permissible. A single cell with a haploid set of chromosomes was found in a female patient with the highest body burden. An increased rate of nonagglutinable red cells was a frequent but not regular finding in the exposed group and no relation to the size of the body burden could be established. /Strontium-90 and radium-226/[Muller J et al; Hlth Phys 12 (8): 993-1006 (1966)] **PEER REVIEWED**

/OTHER TOXICITY INFORMATION/ For most internal dosimetry purposes, strontium-90 and yttrium-90 are the nuclides of concern. These nuclides are found in equilibrium in virtually all circumstances under which exposure is likely. Although strontium separation operations have been performed in which pure strontium-90 might be obtained, the rapid ingrowth of the yttrium-90 decay product results in the secular equilibrium condition being achieved within about 2 weeks after separation. Thus, even if an exposure to pure strontium-90 occurred involving significant metabolic uptake and internal deposition, within about 2 weeks of exposure equal quantities of both nuclides would be present in the body. /Strontium-90 and Yttrium-90/[Pacific Northwest National Laboratory; HANFORD: Radiation and Health Technology Methods and Models of the Hanford Internal Dosimetry Program. PNNL-MA-860 (2003) Available from, as of October 4, 2006: http://www.pnl.gov/eshs/pub/pnnl860/pnnl860.pdf] **PEER REVIEWED**

/OTHER TOXICITY INFORMATION/ /BONE/ The hazard of strontium-90 is primarily that of internal contamination. In the body, it is deposited mainly in the bones and due to its long biological half-life, it may result in beta-ray induced hemopoietic tissue lesions and malignant bone growth. /Strontium-90/[International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983., p. 2112] **PEER REVIEWED**

/OTHER TOXICITY INFORMATION/ /HEMATOPOIETIC SYSTEM/ The Techa River population exposed to chronic combined external gamma radiation and internal radiation due to strontium-90 and cesium-137 exhibited alterations in hematological parameters, including leukopenia, thrombocytopenia, and granulocytopenia. These effects were observed in a portion of the exposed population that received radiation doses to the bone marrow at rates in excess of 30-50 rem (0.3-0.5 Sv) per year. These ... exposures were to multiple sources of radiation. /Strontium-90 and cesium-137/[DHHS/ATSDR Toxicological Profile for Strontium p 89 (2004)] **PEER REVIEWED**

/OTHER TOXICITY INFORMATION/ /GENOTOXICITY/ Radioactive strontium has been shown to be genotoxic to human cells in vitro. In lymphocytes from freshly-drawn human blood, doses of 0.2 to 5.0 Gy (0.002 to 0.05 rad) increased the frequency of chromosomal aberrations. Acentric aberrations (acentrics and double minutes) increased at > or = to 0.2 Gy (0.002 rad), dicentric aberrations increased at > or = to 0.5 Gy (0.005 rad), and there was a slight indication that the frequency of centric rings increased at > or = to 3.0 Gy (0.03). In the same study, results of an electrophoretic assay (comet assay) on single exposed lymphocytes revealed that DNA damage ... occurred at doses as low as 0.2 Gy (0.002 rad)... . Dose-related increases in micronucleus formation, predominantly derived from acentric chromosomes, were reported in human lymphocytes irradiated at doses between 0.3 and 3.0 Gy (0.003 and 0.030 rad). /Radioactive strontium/[DHHS/ATSDR Toxicological Profile for Strontium p 117 (2004)] **PEER REVIEWED**

DRUG WARNINGS:

As an adjunct to surgical removal of the pterygium, a solid strintium-90 source is apposed to the site in order to reduce neovascularization. Several clinical studies reported complications resulting from this procedure. ... Atrophy of the sclera occurred after a dose of 1,600 rad from 90-Sr. In a later study, 78 eyes in 62 patients were treated with 1,080 rad (10.8 Gy) of beta radiation from a 90-Sr source repeated at weekly intervals (total dose 3,200 rad; 32 Gy). Six patients were retreated ... One eye, which had received treatments of 5,380 rad (53.8 Gy) each to two adjacent fields, developed keratitis of the cornea. Other complications noted were telangiectasis of the conjunctiva (27%), scarring of the conjunctiva (14%), and scarring of the cornea (3%). ... A complication rate of 1.8% was reported for a study of 490 eyes (399 patients) that received doses between 31 and 42 Gy (3,100 - 4,200 rad) in four or five fractions over 29 days. Scleral thinning, not severe enough to require treatment, was reported for four eyes in three patients.[DHHS/ATSDR Toxicological Profile for Strontium p 107-8 (2004)] **PEER REVIEWED**

MEDICAL SURVEILLANCE:

A worker who may have received an intake of strontium should be scheduled for a whole body count and a urine sample. These initial measurements can be used to confirm an intake and provide preliminary estimates of the magnitude of potential doses. Suitable urine samples can include a single voiding, overnight, or simulated 24-hour sample, depending on the potential severity of intake (the higher the severity, the more important prompt information becomes). ... Long-term monitoring of urinary excretion following a strontium-90 intake may be required to validate the excretion model or to ensure that potential additional intakes do not go undetected. The establishment of a sampling frequency for such monitoring is dependent upon the nature of the exposure, magnitude of deposition, and likelihood for additional exposure. Appropriate long-term follow-up monitoring should be determined as part of the exposure evaluation.[Pacific Northwest National Laboratory; HANFORD: Radiation and Health Technology Methods and Models of the Hanford Internal Dosimetry Program. PNNL-MA-860 (2003) Available from, as of October 4, 2006: http://www.pnl.gov/eshs/pub/pnnl860/pnnl860.pdf] **PEER REVIEWED**

Workers potentially exposed to strontium-90 should be on an annual or biennial urinalysis bioassay program. Such programs should be easily capable of detecting class D intakes resulting in committed effective dose equivalents less than 100 mrem. Similar monitoring programs applied to inhalation class Y are capable of detecting committed effective dose equivalents below 200 mrem.[Pacific Northwest National Laboratory; HANFORD: Radiation and Health Technology Methods and Models of the Hanford Internal Dosimetry Program. PNNL-MA-860 (2003) Available from, as of October 4, 2006: http://www.pnl.gov/eshs/pub/pnnl860/pnnl860.pdf] **PEER REVIEWED**

The standard method of bioassay for strontium is by analysis of urine excreta samples. /For/ class D material, its rapid transport to the systemic compartment makes urine sampling an accurate, reliable, and convenient means for bioassay monitoring. In addition, the lack of any readily detectable gamma emissions makes in vivo detection somewhat ineffective, although if sufficient strontium is present, the bremsstrahlung can be detected by in vivo counting. Fecal samples can also be analyzed; however, their collection is more difficult ...[Pacific Northwest National Laboratory; HANFORD: Radiation and Health Technology Methods and Models of the Hanford Internal Dosimetry Program. PNNL-MA-860 (2003) Available from, as of October 4, 2006: http://www.pnl.gov/eshs/pub/pnnl860/pnnl860.pdf] **PEER REVIEWED**

Direct in vivo measurement of strontium-90 in the skeleton is possible by counting the bremsstrahlung from its decay. This procedure is subject to substantial interference by any other gamma- and beta emitting nuclides that might be present. Indications are that a retained quantity in the skeleton of about 100 nCi might be detectable by head counting, however, there is no calibration for this measurement. ... It is generally recommended that in vivo measurements be used only as indicators of the potential for strontium being present, and that evaluations of any strontium intake be based on urine samples.[Pacific Northwest National Laboratory; HANFORD: Radiation and Health Technology Methods and Models of the Hanford Internal Dosimetry Program. PNNL-MA-860 (2003) Available from, as of October 4, 2006: http://www.pnl.gov/eshs/pub/pnnl860/pnnl860.pdf] **PEER REVIEWED**

PROBABLE ROUTES OF HUMAN EXPOSURE:

NIOSH (NOES Survey 1981-1983) has statistically estimated that 4,656 workers (533 of these are female) are potentially exposed to strontium-90 in the US(1). Workers employed in the nuclear industry may be exposed to strontium-89 and strontium-90 through oral, dermal, and inhalation routes(2). The radioactive half-life of strontium-89 is short in comparison to strontium-90; therefore, the potential exposure to workers and the general population is considerably lower for strontium-89 as compared to strontium-90. A case of accidental inhalation and dermal exposure to strontium-90 was reported for two workers handling waste containers holding strontium-90 waste(3). The strontium-90 intake for one of the workers was estimated as 2.6X10+5 Bq and was 6.6X10+4 Bq for the second employee(3).[(1) NIOSH; National Occupational Exposure Survey. Sr-90. 10098-97-2. Available http://www.cdc.gov/noes/noes1/x3148sic.html as of Sept 30, 2005. (2) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004) (3) Navarro T, Lopez MA; Radiat Prot Dosim 79: 67-70 (1998)] **PEER REVIEWED**

Current exposure of the general US population to strontium-89 and strontium-90 is expected to be low since atmospheric testing of nuclear weapons has been discontinued for several years and Chernobyl-related fallout was low in the United States(1). The primary route of exposure is through oral ingestion of foods and water containing radioactive strontium and possibly inhalation of aerosols(1).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

Plants acquire strontium-90 through atmospheric deposition and uptake through the roots. Root uptake from soil is the primary pathway. Cows, reindeer and other animals consume vegetation containing strontium-90 and ultimately it may be transferred to the human food chain via milk, beef, etc(1).[(1) WHO; Selected radionuclides: Tritium, carbon-14, krypton-85, strontium-90, iodine, caesium-137, radon, plutonium. Environmental Health Criteria 25. Geneva: World Health Organization. (1983)] **PEER REVIEWED**

BODY BURDEN:

The distributions of strontium-90 in the body are significantly different for males and females(1). As expected, the highest concentrations of strontium-90 are measured in the boney tissue. Males averaged and females averaged 10.4 and 65 pCi/kg (0.38 and 2.4 Bq/kg) wet weight, respectively(1). Males had a much higher concentration of strontium-90 in muscle tissue compared to females. The heart and psoas muscles had respective concentrations of strontium-90 for men averaging 13.9 and 18.7 pCi/kg (0.51 and 0.69 Bq) wet weight versus respective concentrations of 7.4 and 1.9 pCi/kg (0.27 Bq/kg and 70 mBq/kg) wet weight for females (1). The strontium-90 activities in teeth collected from the Ukraine ranged from 0.027 to 0.44 pCi/g(1). A worker that was accidently exposed to strontium-90 while handling waste containers had a strontium-90 urinary excretion rate of approximately 544 Bq/day, one day post exposure(2). The urinary excretion rate decreased exponentially and was < 1 Bq/day 212 days later(2).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004) (2) Navarro T, Lopez MA; Radiat Prot Dosim 79: 67-70 (1998)] **PEER REVIEWED**

AVERAGE DAILY INTAKE:

The AVDI of strontium-90 in the US peaked in 1963 at approximately 1.1 Bq/day and has steadily decreased(1). The current AVDI of strontium-90 in the US is less than 0.05 Bq/day(1).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

EMERGENCY MEDICAL TREATMENT:

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LIFE SUPPORT:

o This overview assumes that basic life support measures have been instituted.

CLINICAL EFFECTS:

0.2.1 SUMMARY OF EXPOSURE

0.2.1.1 ACUTE EXPOSURE

A) SOURCES: IONIZING RADIATION: Nuclear emissions that have sufficient energy to ionize atoms and remove one or more electrons from the orbit of other atoms. Radiation injuries occur secondary to exposure to ionizing radiation (eg, alpha particles, beta particles, gamma rays, x-rays, and neutrons). The radioactive exposure may be due to external irradiation (source at some distance from the body) or internal contamination (ingestion, inhalation, absorption through skin or wounds). Acute radiation syndrome may occur after total or near total body irradiation with a high dose of ionizing radiation over a short period of time. The most common radionuclides in the atmosphere are: radon-222, tritium, iodine-129, strontium-90, cesium-137, and krypton-85. Radioactive materials of military significance (Military Five) include: Tritium (3H), uranium (235U, 238U), plutonium (239Pu), and americium (241Am).

B) TOXICOLOGY: The response to exposure to ionizing radiation varies by cell type and is largely a function of the rate of cell replication or the cell cycle length. Cells are most vulnerable to the effects of radiation during mitosis; therefore, the tissue with the most mitotically active cells will be the most damaged. Spermatogonia, the cells of the gastrointestinal tract, and hematopoietic cells such as lymphocytes and erythroblasts are the most sensitive, while collagen-producing cells, muscle cells, and bone cells are less affected since they are not as mitotically active. Thus, the 3 syndromes that result are hematopoietic, gastrointestinal, and neurovascular, based on these decreasing radiation sensitivities. Increasing doses of ionizing radiation lead to increasing damage to the cells that are more radioresistant.

C) EPIDEMIOLOGY: Radiation exposures are rare, but can be life-threatening.

D) WITH POISONING/EXPOSURE

1) The clinical syndromes described for acute radiation syndrome (ARS) follow 4 clinical phases: prodromal, latent, manifest illness, and recovery (or death).

a) HEMATOPOIETIC SYNDROME: Dose (gamma equivalent values): Greater than 0.7 Gy (greater than 70 rads);

mild symptoms may develop following doses as low as at 0.3 Gy (30 rads).

1) Prodromal stage: Anorexia, nausea, vomiting; onset 1 hour to 2 days postexposure; lasts minutes to days
2) Latent stage: Patients may appear well; stem cells are dying; lasts 1 to 6 weeks
3) Manifest illness stage: Anorexia, fever, malaise. All blood cell counts decrease for weeks. Death from infection or hemorrhage. Increasing dose decreases survival. Most deaths within few months.
4) Recovery: Bone marrow cells begin to repopulate the marrow. Large proportion will recover from few weeks up to 2 years. Death may occur at 1.2 Gy (120 rads). LD50/60 approximately 2.5 to 5 Gy (250 to 500 rads).

b) GASTROINTESTINAL SYNDROME: Dose (gamma equivalent values): Greater than 10 Gy (greater than 1000 rads); some symptoms may develop following doses as low as 6 Gy (600 rads).

1) Prodromal stage: Anorexia, severe nausea, vomiting, cramps, diarrhea. Onset within few hours; lasts 2 days.
2) Latent stage: Patients may appear well. Stem cells and gastrointestinal lining cells are dying; lasts less than 1 week.
3) Manifest illness stage: Malaise, anorexia, severe diarrhea, fever, dehydration, electrolyte imbalance. Death from infection, dehydration, and electrolyte imbalance. Death may occur within 2 weeks.
4) Recovery: LD100 is about 10 Gy (1000 rads).

c) CNS/CARDIOVASCULAR SYNDROME: Dose (gamma equivalent values): Greater than 50 Gy (greater than 5000 rads). Some symptoms may develop following doses as low as 20 Gy (2000 rads).

1) Prodromal stage: Extreme nervousness, confusion, severe nausea, vomiting, watery diarrhea, loss of consciousness, burning skin sensation. Onset within minutes; lasts minutes to hours.
2) Latent stage: Partial functionality may return. May last for hours but usually less.
3) Manifest illness stage: Return of watery diarrhea, seizures, coma. Onset 5 to 6 hours postexposure. Death within 3 days.
4) Recovery: No recovery expected.

2) CUTANEOUS RADIATION SYNDROME (CRS): Exposure to radiation can damage the basal cell layer of skin, resulting in inflammation, erythema, and dry or moist desquamation. Epilation may occur when hair follicles are damaged. A transient and inconsistent erythema and pruritus may occur within a few hours of exposure. Patients may develop intense reddening, blistering, and ulceration of the irradiated site during a latent phase that lasts from a few days up to several weeks. Although healing can occur, very large doses can cause permanent hair loss, damage sebaceous and sweat glands, atrophy, fibrosis, decreased or increased skin pigmentation, and ulceration or necrosis of the tissue. Patients may develop skin damage without ARS following radiation dose to the skin, especially after acute exposures to beta radiation or X-rays.
3) Hypothyroidism or hyperthyroidism may occur. Both benign and malignant thyroid tumors have been associated with ionizing radiation exposure.
4) COMBINED INJURY: Patients with combined injuries (trauma, thermal, chemical injury, and radiation

exposure) may develop immunosuppression, delayed healing, pancytopenia, and other symptoms.

0.2.3 VITAL SIGNS

0.2.5 CARDIOVASCULAR

0.2.5.1 ACUTE EXPOSURE

A) WITH POISONING/EXPOSURE

1) Hypotension may occur following the neurovascular stage or due to hypovolemia.

0.2.6 RESPIRATORY

0.2.6.1 ACUTE EXPOSURE

A) Pulmonary radiation injury may result in radiation pneumonitis and radiation pulmonary fibrosis.

0.2.12 FLUID-ELECTROLYTE

0.2.12.1 ACUTE EXPOSURE

A) WITH POISONING/EXPOSURE

1) Fluid and electrolyte losses generally occur during the gastrointestinal syndrome.

0.2.13 HEMATOLOGIC

0.2.13.1 ACUTE EXPOSURE

A) WITH POISONING/EXPOSURE

1) A decrease in neutrophils may reflect the degree of exposure. Leukemia may develop following significant exposures. Pancytopenia may occur and predisposes to infections and sepsis, especially in patients with concomitant traumatic injuries.

0.2.14 DERMATOLOGIC

0.2.14.1 ACUTE EXPOSURE

A) WITH POISONING/EXPOSURE

1) Thermonuclear burns may occur.

0.2.20 REPRODUCTIVE HAZARDS

A) Four major effects of ionizing radiation on the fetus include: growth retardation; severe congenital malformations (including errors of metabolism); embryonic, fetal, or neonatal death; and carcinogenesis. Fetal risk is noted at exposures above 10 rem. In early pregnancy, fetal death may occur. Later in pregnancy, radiation exposure may be teratogenic or may cause fetal growth retardation.

B) Occupational limits: Fetal dose (declared pregnancy): 0.5 rem (5 mSv). Although radiation doses to the embryo or fetus in the uterus is lower than the doses to its mother, health effects of exposure to ionizing radiation in human embryo and fetus can be severe, even at radiation doses too low to immediately affect the mother. Low-level ionizing radiation does not appear to increase the risk of teratogenicity. Consider doses of radioactive materials in specific fetal organs or tissues (eg, iodine-131 or iodine-123 in thyroid; iron-59 in the liver; gallium-67 in the spleen, strontium-90 and yttrium-90 in the skeleton). Approximately 5 Gy (500 rads) dose before 18 weeks' gestation can kill 100% of human embryos or fetuses; 50% of embryos may die with a fetal dose of 1Gy (100 rads).

C) Cesium has been shown to penetrate the human placenta and be present in breast milk in mothers following exposures.

D) Impaired fertility, including abnormal sperm production and impaired sexual function, has been reported in men. It is possible that radiation exposure in women may affect the viability of the ova and the function of the endocrine system which is responsible for production of some female sex hormones.

0.2.21 CARCINOGENICITY

0.2.21.2 HUMAN OVERVIEW

A) Ionizing radiation has carcinogenic effects in many tissues. The major toxicity of low- and moderate-dose ionizing radiation is cancer induction. Acute ionizing radiation exposure survivors have increased long-term cancer risks. A dose-response relationship exists between exposure to ionizing radiation and the risk for the subsequent development of cancer.

0.2.22 GENOTOXICITY

A) Ionizing radiation is genotoxic and causes breaks in the structure of DNA, resulting in mutations or chromosomal structural aberrations. Double strand breaks in the mutagenic and carcinogenic effects of radiation have been reported. Incorrectly rejoined break leads to DNA mis-repair which in turn leads to DNA deletions and rearrangements. Large scale changes in DNA structure appear to be typical of most radiation-induced mutations.

B) CHROMOSOMAL ABERRATIONS

1) Hospital workers exposed to low levels of ionizing radiation had 13 and 11 times greater frequencies of chromosomal aberrations in peripheral lymphocytes compared with unexposed controls. Workers were exposed to mean x-ray doses of 1.84 millisieverts/yr and 1.67 millisieverts/yr for 3 to 20 years. These workers had a higher frequency of chromosomal gaps and breaks, endoreduplications, hyperdiploidies, and chromosomal loss (Paz-y-Mino et al, 1995).

2) Nuclear medicine and radiology hospital workers had a mean group frequency of chromosomal aberrations (chromosomal gaps and breaks) in peripheral lymphocytes significantly higher than that of unexposed controls (Hagelstrom et al, 1995).

3) The frequency of chromosomal aberrations in the peripheral lymphocytes of hospital radiodiagnostic, radiotherapy, and nuclear medicine employees was greater than in controls. There were no significant differences between exposed and control groups in the frequency of chromatid gaps and breaks, while significant differences were noted for acentric fragments with or without chromosomal gaps and breaks and total structural aberrations (Barquinero et al, 1993).

4) The was a statistically significant increased total aberration frequency in peripheral lymphocytes in a small group of civilian air crew members compared with controls (Romano et al, 1997). Air crew members are presumed to have increased exposure to cosmic radiation than the general public because of more time spent at high altitudes during flight (Zwingmann et al, 1998) Okansen, 1998; (Friedberg et al, 1989).

5) Two years after total-body or total-body plus partial-body exposure to gamma radiation from an accident in Estonia, 5 persons had a stable level of translocations present in peripheral blood lymphocytes (Lindholm et al, 1998).

6) In 100 medical workers exposed to x-rays, there was no time-dependent recovery of chromosomal aberrations in peripheral blood lymphocytes (Kasuba et al, 1998).

7) Children exposed to low doses of ionizing radiation from the Chernobyl disaster had more acentric fragments in peripheral blood lymphocytes than did control subjects, but there were no significant differences in chromosome or chromatid breaks (Grollino et al, 1998).

8) Chromosome aberrations in Norwegian reindeer following

the Chernobyl accident (radiocesium exposure) appeared to affect mainly calves during the immediate post-accident period in the highest radiation fallout areas (Roed & Jacobsen, 1995).

9) Increased chromosomal aberrations, especially acentric fragments, were found in lymphocytes from hospital workers exposed to low doses of ionizing radiation (1.6 to 42.71 millisieverts). No dose-effect relationship was seen (Barquinero et al, 1993). In a group of 47 children exposed to radiation in the Chernobyl incident, low frequencies of chromosome aberrations were evident several years later (Padovani et al, 1993).

10) Chromosomal translocations in persons who lived in houses (up to 16 years) in Taiwan contaminated with cobalt-60 has been reported. Compared with controls (no exposure to cobalt-60), the overall translocation yield in the residents was 5 times higher. Chromosomes 2, 4 and 12 were affected in 500 metaphases per person. The FISH method for reciprocal chromosomal translocations was used (Chen et al, 2000).

C) MUTAGENICITY

1) Japanese atomic bomb survivors have been followed for possible heritable effects from acute ionizing radiation exposure. Even in this population, no clearly demonstrable induced heritable defects have been found (Otake & Schull, 1984). No significant differences in mutation rates in DNA repetitive sequences were found in children of atomic bomb survivors whose parents received a mean gonadal dose of 1.9 sieverts, in comparison with unexposed controls (Satoh et al, 1996).

2) Workers exposed to low levels of ionizing radiation had increased frequencies of hprt-mutated lymphocytes and changed CD4/CD8 lymphocyte subset ratios (Siefert et al, 1993). A 4.6-fold increase in hprt mutations in blood cells was seen in Brazilian children exposed to 15 to 70 centi-gray units (cGy) during a radiological accident (Saddi et al, 1996). A doubling dose of 173 (+/- 47) cGy was seen for inducing hprt mutation and micronuclei in victims of a Cs-137 radiological accident in Goiania, Brazil (Dacruz et al, 1997).

3) Persons living near a uranium processing site did not have increased frequencies of mutated somatic cells, as measured by hprt mutations, loss of glycophorin A alleles, or micronuclei (Wones et al, 1995).

4) Increased glycophorin A mutations were seen in former Australian uranium miners 30 years after last exposure (Shanahan et al, 1996).

5) Human cells containing mutant p53 proteins did not have delayed cell replication after irradiation; this is consistent with the occurrence of mutated p53 proteins in some cancers (Zolzer et al, 1995). In related studies, cells from patients with ataxia telangiectasia (AT) had a reduced or delayed increase in p53 protein after gamma-irradiation (Birrell & Ramsay, 1995). Cells from persons heterozygous for AT had an intermediate response. Cells from most breast cancer patients were essentially normal in their response, but 18% of the patients responded in the range of AT heterozygotes. This test of p53 induction may be useful in identifying persons at increased risk of DNA-damaging effects of ionizing radiation (Birrell & Ramsay, 1995). AT is a heritable disease characterized by increased radiation sensitivity and risk for cancer.

6) In limited studies, the serum of persons exposed to ionizing radiation contains clastogenic factors, which have persisted for over 30 years in A-bomb survivors. Such factors have been found in dose-related levels in the serum of 33 of 47 recovery workers from the Chernobyl incident (Emerit et al, 1995).

LABORATORY:

A) Monitor vital signs and repeat every 2 hours for symptomatic patients.

B) Obtain a baseline CBC with differential and absolute lymphocyte count, then every 4 hours for the first 8 hours, then every 6 hours for the subsequent 40 to 48 hours, then daily. Lymphocyte kinetics and neutrophil/lymphocyte ratio are sensitive indicators of radiation dose.

C) Monitor for presence of sepsis or opportunistic infections, particularly in the presence of bone marrow depression and loss of intestinal mucosa.

D) A baseline serum amylase level should be obtained to evaluate for parotitis; repeat in 24 hours. Exposures above 0.5 Gy (50 rads) will result in a significant elevation of serum amylase. Electrolyte levels should be obtained when necessary.

E) Obtain blood and tissue typing, if the examination suggests a high-dose exposure. These patients may need bone marrow, umbilical cord blood, or peripheral stem cells due to pancytopenia.

F) If the history indicated possible inhalation or ingestion of radioactive materials, a 24-hour urine collection should be obtained for analysis, using any properly labeled sealed container. In addition, if inhalation may have occurred, nasal swabs should be obtained from each nostril, the amount of radiation in each should be measured with a handheld counter, and the 2 counts should be added. This amount divided by 0.1 provides a useful approximation of the inhaled dose, and this result can be compared with available tables that indicate the Annual Limit on Intake to determine if treatment is required (www.orise.orau.gov/reacts).

G) Cytogenetic dosimetry, the gold standard method of measurement, should be ordered and obtained after 24 hours to determine the actual dose absorbed by the patient. However, there are only 2 laboratories in the United States that perform cytogenetic dosimetry and results are not available for a few days.

H) Monitor for neurological symptoms, including a steadily deteriorating state of consciousness with coma and/or seizures during the neurovascular syndrome following very high acute radiation doses.

TREATMENT OVERVIEW:

0.4.2 ORAL EXPOSURE

A) MANAGEMENT OF TOXICITY

1) Stabilize all patients from their traumatic injuries prior to evaluating them for radiation injuries. Although high intensity external radiation can cause tissue damage (eg, skin burns or marrow depression), it does not make the patient radioactive. However, all staff should be in scrubs covered with a water resistant gown or a Tyvek(R) suit. A cap, mask, and shoe covers should be worn, and 2 pairs of plastic gloves worn with the first pair taped to the gown or suit. Dosimeters should be worn at the collar but under the protective clothing.

2) External decontamination should be performed, which is

largely accomplished by removing and bagging the clothing, and washing the skin with warm water and soap. The history obtained at the scene is of great importance. The exact type of exposure (ie, internal versus external and partial versus whole body exposure) should be obtained. The main goals of therapy for acute radiation syndrome are prevention of neutropenia and sepsis. Examine the patient and repeat at 6 hours and 12 hours. Monitor vital signs, including temperature; the sooner the temperature rises, the greater the dose received. Trauma or other urgent medical or surgical situations should be managed prior to treatment for radiation exposure.

3) INGESTION: Patients who ingested any radioactive matter should receive aluminum hydroxide or magnesium carbonate antacids to reduce absorption. Treat patients with persistent nausea and vomiting with granisetron or ondansetron. Early oral feedings are recommended to maintain gut function. All emesis should be collected for the first few days, saving for later analysis. Antidiarrheals may be used to control diarrhea. Internal contamination may require treatment with radiation countermeasure agents such as potassium iodide (radioactive iodine exposure), prussian blue (cesium and thallium exposure), or chelating agents (plutonium, americium, curium exposure). However, these agents do not protect against external radiation absorption and acute radiation syndrome.
4) Colony-stimulating factor treatment should begin within 24 to 72 hours of exposure when granulocyte levels are falling, with daily therapy continued until the absolute neutrophil count increases to more than 1000 cells/mm(3). Patients who develop infection without neutropenia should have antibiotic therapy directed towards the source of infection and the most likely pathogen.
5) LOCALIZED RADIATION INJURY: Localized radiation injury may also occur in conjunction with acute radiation syndrome, usually presenting with delayed erythema and desquamation or blistering 12 to 20 days after exposure. Treatment includes pain management, infection prevention, and vasodilators.
6) PALLIATIVE CARE: Patients who vomited within a few minutes of exposure, with diarrhea developing in less than an hour, fever developing in less than 1 hour, severe headache, a possible history of loss of or altered consciousness, abdominal pain, parotid pain, erythema, and possible hypotension have likely received a lethal dose with poor prognosis. Palliative care should be started immediately, with initial treatment in the ICU if resources allow.
7) Further information is available from the CDC (http://www.bt.cdc.gov/radiation/) and the United States Department of Health and Human Services (http://www.remm.nlm.gov/). Emergency consultation services are also available through the Radiation Emergency Assistance Center/Training Site (REAC/TS) 24 hours a day, 7 days a week at 865-576-1005 (http://orise.orau.gov/reacts/).

B) DECONTAMINATION

1) DERMAL: Most decontamination (90%) is accomplished by removal of the outer clothing and shoes. A radiation detector passed over the body (held at a consistent distance from the body) can detect residual

contamination. Further decontamination is accomplished by washing with warm soap and water, with gentle brushing while covering open wounds. Reduction of radiation to less than 2 times the background level is the goal of decontamination. Contaminated wounds require further effort. Abrasions are decontaminated with warm water and soap. Lacerations may require excision of contaminated tissue. Punctate lesions may be successfully cleaned using a water pick or oral irrigator. Shrapnel should be removed with forceps.

2) INGESTION: Patients who ingested any radioactive matter should receive aluminum hydroxide or magnesium carbonate antacids to reduce absorption. Gastric lavage may be used if ingestion occurred within 1 to 2 hours, and large ingestions may benefit from cathartics and enemas.

3) EYES: Obtain an x-ray to rule out presence of shrapnel in globe. If corneal contamination is present and globe is intact, carefully irrigate eyes with copious amounts of saline or water. Never irrigate a ruptured globe. To avoid contamination of nasolacrimal duct, direct irrigation stream away from inner canthus and toward outer canthus. Monitor the eyes for conjunctivitis after decontamination. The irrigation fluid should be tested frequently for residual radioactivity. Collect, store, and label irrigation fluid properly for forensic evaluation and proper disposal.

C) RADIATION INFORMATION

1) Several historical points should be quickly obtained when whole-body irradiation is a possibility: (1) location when the potential exposure occurred; (2) amount of possible shielding, including position inside a building; (3) amount of time outside away from shielding; and (4) occurrence of any vomiting or diarrhea. It should be documented whether any decontamination has occurred, and if any loss of consciousness was experienced. If trauma occurred, the mechanism of injury should be determined, and any medication use and allergy history recorded.

MEASUREMENT OF RADIATION: In patients who have inhaled, ingested, or absorbed radioactive material through wound, direct measurement of radiation within the patient is a possible to guide therapy. Ingested radioactivity can be measured from collected urine. If inhalation may have occurred, nasal swabs should be taken as soon as possible in order to determine the approximate radiation exposure; combine the 2 measurements and divide by 0.1 to obtain the inhaled amount of radiation. Similar measurements may be taken from contaminated wounds. In all cases, the measurements can be converted into a measure of activity and compared with charts of known annual limits of intake to determine if the amount of radiation internally present is hazardous and requires treatment. Specific medical countermeasures may be employed to treat internal contamination, some of which depend on the specific radionuclide that has been ingested or inhaled.

D) AIRWAY MANAGEMENT

1) Administer 100% oxygen as needed for respiratory support. Endotracheal intubation and mechanical ventilation may rarely be required.

E) ANTIDOTES

1) DEFEROXAMINE

a) USES: Iron, manganese, neptunium, and plutonium.
b) DOSES: Not specified by age: 1 g IM or IV (2 ampules) slowly (15 mg/kg/hr); IM is preferred; repeat as indicated as 500 mg IM or IV every 4 hours for 2 doses; then 500 mg IM or IV every 12 hours for 3 days.

2) DIMERCAPROL
a) USES: Antimony, arsenic, bismuth, gold, lead, mercury, nickel, polonium-210.
b) DOSES: Not specified by age: 300 mg per vial for deep IM use, 2.5 mg/kg (or less) every 4 hours for 2 days, then twice daily for 1 day then once daily for days 5 to 10.

3) EDETATE CALCIUM DISODIUM
a) USES: Cadmium, chromium, cobalt, copper, iridium, lead, manganese, mercury, nickel, plutonium, ruthenium, yttrium, zinc, zirconium.
b) DOSES: Not specified by age: 1000 mg/m(2)/day added to 500 mL dextrose 5% normal saline over 8 to 12 hours.

4) DTPA, CALCIUM OR ZINC
a) USES: Plutonium-239, Americium-241, Curium-244.
b) DOSES: ADULTS: 1 g in 5 mL IV push over 3 to 4 minutes or IV infusion over 30 minutes diluted in 250 mL of 5% dextrose in water, Normal Saline (NS), or Ringers Lactate. Nebulized inhalation: 1 g in 1:1 dilution with water or NS. CHILDREN (age under 12 years): 14 mg/kg IV loading dose as soon as possible; MAX: 1 g.

5) PENICILLAMINE
a) USES: Antimony, bismuth, copper, gallium, gold, mercury, palladium, polonium.
b) DOSES: Not specified by age: 250 mg daily orally between meals and at bedtime; may increase to 4 or 5 g daily in divided doses.

6) POTASSIUM IODIDE
a) USES: radioactive iodine.
b) DOSES: ADULTS: 130 mg orally daily for ingestion of radioactive iodine. CHILDREN (age 12 to 18 years, weight greater than 150 pounds): 130 mg orally daily for ingestion of radioactive iodine. CHILDREN (age 12 to 18 years, weight less than 150 pounds): 65 mg orally daily for ingestion of radioactive iodine. CHILDREN (age 3 to 12 years): 65 mg orally daily for ingestion of radioactive iodine. CHILDREN (age 1 month to 3 years): 32.5 mg orally daily for ingestion of radioactive iodine. CHILDREN (birth to 1 month): 16.25 mg orally daily for ingestion of radioactive iodine.

7) PROPYLTHIOURACIL
a) USES: Iodine-131.
b) DOSES: Not specified by age: 2 tabs (50 mg each) 3 times daily for 8 days.

8) PRUSSIAN BLUE
a) USES: Cesium-137, thallium-201, rubidium.
b) DOSES: ADULTS: 3 g orally 3 times daily. CHILDREN (age 2 to 12 years): 1 g orally 3 times daily.

9) SUCCIMER
a) USES: Arsenic, bismuth, cadmium, cobalt, lead, mercury, polonium.
b) DOSES: CHILDREN: initial, 10 mg/kg or 350 mg/m(2) orally every 8 hours for 5 days. Reduce frequency of administration to 10 mg/kg or 350 mg/m(2) every 12 hours (two-thirds of initial daily dose) for an additional 2 weeks of therapy (course of therapy: 19 days).

F) NAUSEA AND VOMITING

1) Treat patients with persistent nausea and vomiting with

granisetron or ondansetron. Early oral feedings are recommended to maintain gut function.

G) DIARRHEA

1) Antidiarrheals may be used for the control of diarrhea (eg, loperamide or diphenoxylate/atropine).

H) MYELOSUPPRESSION

1) Colony-stimulating factors (FILGRASTIM: ADULTS: 2.5 to 5 mcg/kg once daily subQ. SARGRAMOSTIM: ADULTS: 5 to 10 mcg/kg once daily subQ. PEGFILGRASTIM: ADULTS: 6 mg once subQ) should begin within 24 to 72 hours of exposure when granulocyte levels are falling, with daily therapy continued until the absolute neutrophil count increases to more than 1000 cells/mm(3). Patients who develop infection without neutropenia should have antibiotic therapy directed towards the source of infection and the most likely pathogen. If febrile neutropenia develops, consultation with infectious disease and hematology specialists should be obtained, and guidelines on febrile neutropenia from the Infectious Disease Society of America should be followed for appropriate antibiotic therapy. Patients who received doses of 7 to 10 Gy (700 to 1000 rads) should be considered for bone marrow stem cell transplants. The Radiation Injury Treatment Network was founded to assist in situations in which profound damage to the bone marrow has occurred, and it can be reached at: http://bloodcell.transplant.hrsa.gov/ABOUT/RITN/index.html. If transfusion of blood products is required, all products should leukoreduced and irradiated to 25 Gy in order to avoid a transfusion-related graft-vs-host reaction.

I) HYPOTENSION

1) Treat hypotension with intravenous fluids; if hypotension persists, administer vasopressors.

J) SEIZURES

1) IV benzodiazepines; barbiturates or propofol if seizures recur or persist.

K) ENHANCED ELIMINATION PROCEDURE

1) In one in vitro study, charcoal hemoperfusion was NOT effective in decreasing radioactivity in artificial media containing cesium-137.

L) PATIENT DISPOSITION

1) HOME CRITERIA: Any patient who is asymptomatic, totally decontaminated as indicated by survey, and has a normal CBC and platelet count may be safely discharged. Follow-up instructions should include a repeat CBC in 48 hours and reevaluation following the onset of any gastrointestinal symptoms (eg, nausea, vomiting, and diarrhea).

2) ADMISSION CRITERIA: Admission is required for fluid and electrolyte therapy if severe vomiting and diarrhea are present. Patients manifesting thrombocytopenia, granulocytopenia, and/or lymphopenia require hospital admission. Hospital admission is also necessary for standard indications for multiple trauma or burns associated with radiation exposure.

3) CONSULT CRITERIA: For patients with localized injury, referral may be required for plastic surgery, grafting, or amputation.

4) PATIENT-TRANSFER CRITERIA: Initially, patients should be field-triaged to a facility designated for handling radioactively-contaminated patients. Other conditions (eg, multiple trauma) may necessitate transporting

patients to a trauma center. After stabilization, decontamination, and initial evaluation, patients with the hematopoietic syndrome should be transferred to a facility with expertise in the treatment of pancytopenia. If transfer is indicated, it should be undertaken on the first day or as soon as possible.

M) PITFALL

1) Early symptoms of radiation exposure may be delayed or not evident (eg, myelosuppression). Appropriate therapy may be delayed due to failure to contact a radiation specialist. Beware of secondary exposures that may come from rescuers who were also exposed. History of radiation exposure may be difficult to obtain in some settings.

N) KINETICS

1) Systemic contamination will occur following ingestion, inhalation, skin absorption, or wound contamination of radioactive material. Following absorption, a radionuclide crosses capillary membranes through passive and active diffusion mechanisms and then is distributed throughout the body. Rate of distribution to each organ is dependent on organ metabolism, ease of chemical transport, and the affinity of the radionuclide for chemicals within the organ. The organs with the highest capacities for binding radionuclides are the liver, kidney, adipose tissue, and bone due to their high protein and lipid makeup. Each radionuclide has a unique half-life, with half-lives ranging from extremely short (fraction of a second) to millions of years. Samples of some radionuclides and their half-lives are: Tc-99m: 6 hours; I-131: 8.05 days; Co-60: 5.26 years; Sr-90: 28.1 years; Pu-239: 24,400 years; U-238: 4,150,000,000 years.

O) DIFFERENTIAL DIAGNOSIS

1) Local injuries such as chemical or thermal burn, insect bite, skin disease or allergy, trauma; food poisoning, gastroenteritis; chemotherapeutic agents, or myelosuppression agents.

0.4.3 INHALATION EXPOSURE

A) In patients who have inhaled radioactive material, direct measurement of radiation within the patient is possible to guide therapy. Nasal swabs should be taken as soon as possible in order to determine the approximate radiation exposure; combine the 2 measurements and divide by 0.1 to obtain the inhaled amount of radiation. In all cases, the measurements can be converted into a measure of activity and compared with charts of known annual limits of intake to determine if the amount of radiation internally present is hazardous and requires treatment. Specific medical countermeasures may be employed to treat internal contamination, some of which depend on the specific radionuclide that has been inhaled.

B) Refer to ORAL OVERVIEW AND MAIN SECTIONS for specific treatment information.

0.4.5 DERMAL EXPOSURE

A) OVERVIEW

1) Most decontamination (90%) is accomplished by removal of the outer clothing and shoes. A radiation detector passed over the body (held at a consistent distance from the body) can detect residual contamination. Further decontamination is accomplished by washing with warm soap and water, with gentle brushing while covering open wounds. Reduction of radiation to less

than 2 times the background level is the goal of decontamination. Contaminated wounds require further effort. Abrasions are decontaminated with warm water and soap. Lacerations may require excision of contaminated tissue. Punctate lesions may be successfully cleaned using a water pick or oral irrigator. Shrapnel should be removed with forceps.

2) Refer to ORAL OVERVIEW AND MAIN SECTIONS for specific treatment information.

RANGE OF TOXICITY:

A) TOXICITY: UNITS: The basic units of measure of ionizing radiation are the rad and the gray (Gy). One rad equals 0.01 joules of energy deposited per kilogram of tissue. One Gy equals 100 rads or 1 joule per kilogram. One sievert (Sv) is equivalent to 100 rems, where 1 rem is 1 Gy multiplied by a factor that depends on the type of radiation received. For gamma radiation, this factor is 1, so that 1 Sv equals 1 Gy equals 100 rads equals 100 rems. For alpha radiation, the factor is 20, so that 1 rad equals 20 rems (or Sv). The factor is 1 for beta radiation and between 3 and 20 for neutron energy.

B) Acute radiation syndrome is a symptom complex following whole body irradiation (greater than 1 Gy). It varies in nature and severity, depending upon: (a) dose measured in gray (Gy), (b) dose rate (dose of radiation per unit of time), (c) dose distribution, and (d) individual susceptibility. Whole-body radiation doses can be divided into potentially lethal (2 to 10 Gy), sublethal (less than 2 Gy), and supralethal (greater than 10 Gy) doses.

1) HEMATOPOIETIC (BONE MARROW) SYNDROME: Dose (gamma equivalent values): Greater than 0.7 Gy (greater than 70 rads); mild symptoms may develop following doses as low as at 0.3 Gy (30 rads). GASTROINTESTINAL SYNDROME: Dose (gamma equivalent values): Greater than 10 Gy (greater than 1000 rads); some symptoms may develop following doses as low as 6 Gy (600 rads). NEUROVASCULAR/CARDIOVASCULAR SYNDROME: Dose (gamma equivalent values): Greater than 50 Gy (greater than 5000 rads). Some symptoms may develop following doses as low as 20 Gy (2000 rads). CUTANEOUS RADIATION SYNDROME: Presentation of Local Radiation Injury defined by dose received: 3 Gy: Epilation (hair loss) begins 14 to 21 days after exposure. 6 Gy: Erythema that may be transient soon after exposure (primary erythema), may again appear 14 to 21 days following exposure (secondary erythema). It may also occur from time to time. 0 to 15 Gy: Dry desquamation is the response of the germinal epidermal layer that is seen 20 days after exposure. Mitotic activity slows in the basal and parabasal layers, the epidermis thins, and large flakes of skin desquamate. 20 to 50 Gy: Wet desquamation occurs as a partial thickness injury. There is intracellular edema, a coalescence of vesicles forming macroscopic bullae, and fibrin coating a wet dermal surface. Radionecrosis may develop as the dose increases. Greater than 50 Gy: Damage to endothelial cells and fibrinoid necrosis of the vasculature cause radionecrosis and ulceration.

ANTIDOTE AND EMERGENCY TREATMENT:

Basic Treatment. Establish a patent airway (oropharyngeal or nasopharyngeal airway, if needed). Suction if necessary. Watch for signs of respiratory insufficiency and assist ventilations if necessary. Administer oxygen by nonrebreather mask at 10 to 15 mL/min. Monitor for shock and treat if necessary. Anticipate seizures and treat if necessary.

Perform routine emergency care for associated injuries. ... Perform routine basic life support care as necessary. /Radioactives I, II, and III/[Currance, P.L. Clements, B., Bronstein, A.C. (Eds).; Emergency Care For Hazardous Materials Exposure. 3Rd edition, Elsevier Mosby, St. Louis, MO 2005, p. 166] **PEER REVIEWED**

Advanced Treatment. Consider orotracheal or nasotracheal intubation for airway control in the patient who is unconscious or is in severe respiratory distress. Monitor cardiac rhythm and treat arrhythmias as necessary. Start IV administration of 0.9% saline (NS) or lactated Ringer's (LR) TKO. For hypotension with signs of hypovolemia, administer fluid cautiously. Watch for signs of fluid overload. Treat seizures with diazepam or lorazepam. Perform routine advanced life support care as needed. Use proparacaine hydrochloride to assist eye irrigation. /Radioactives I, II, and III/[Currance, P.L. Clements, B., Bronstein, A.C. (Eds).; Emergency Care For Hazardous Materials Exposure. 3Rd edition, Elsevier Mosby, St. Louis, MO 2005, p. 166] **PEER REVIEWED**

Special Considerations. Most symptoms from radioactive product exposure are delayed; treat other medical or trauma problems according to normal protocols. An accurate history of the exposure is essential to determine risk and proper treatment modalities. The dose of radiation determines the type and clinical course of exposure: 100 rads: GI symptoms (nausea, vomiting, abdominal cramps, diarrhea). Symptom onset within a few hours. 600 rads: Several GI symptoms (necrotic gastroenteritis) may result in dehydration and death within a few days. Several thousand rads: neurological/cardiovascular symptoms (confusion, lethargy, ataxia, seizures, coma, cardiovascular collapse) within minutes to hours. Bone marrow depression, leukopenia, and infections usually follow severe exposures./Radioactives I, II, and III/[Currance, P.L. Clements, B., Bronstein, A.C. (Eds).; Emergency Care For Hazardous Materials Exposure. 3Rd edition, Elsevier Mosby, St. Louis, MO 2005, p. 167] **PEER REVIEWED**

Emergency and Supportive Measures. Treatment of serious medical problems takes precedence over radiologic concerns. Maintain an open airway and assist ventilation if necessary. Treat coma and seizures if they occur. Replace fluid losses from gastroenteritis with intravenous crystalloid solutions. Treat leukopenia and resulting infections as needed. Immunosuppressed patients require reverse isolation and appropriate broad-spectrum antibiotic therapy. Bone marrow stimulants may help selected patients. Specific drugs and antidotes. Chelating agents or pharmacologic blocking drugs may be useful in some cases of ingestion or inhalation of certain biologically active radioactive materials, if they are given before or shortly after exposure. /From table/ Strontium-90: Alginate or aluminum hydroxide-containing antacids may reduce intestinal absorption of strontium. Barium sulfate may also reduce Sr absorption. /Radiation (Ionizing)/[Olson, K.R. (Ed.); Poisoning & Drug Overdose. 4th ed. Lange Medical Books/McGraw-Hill. New York, N.Y. 2004., p. 329] **PEER REVIEWED**

Decontamination. 1. Exposure to particle-emitting solids or liquids. The victim is potentially highly contaminating to rescuers, transport vehicles, and attending health personnel. 1. Remove victims from exposure, and if their conditions permit, remove all contaminated clothing and wash the victims with soap and water. b. All clothing and cleansing water must be saved, evaluated for radioactivity, and properly disposed of. c. Rescuers should wear protective clothing and respiratory gear to avoid contamination. At the hospital, measures must be taken to prevent contamination of facilities and personnel. d. Induce vomiting or perform gastric lavage if radioactive material has been ingested. Administer activated charcoal, although its effectiveness is unknown. Certain other adsorbent materials may also be effective. e. Contact Radiation Emergency Assistance Center & Training Site (REAC/TS/: telephone (865) 576-3131 or (865) 481-1000)/ and the state radiologic health department for further advice. In some exposures, unusually aggressive steps may be needed (eg, lung lavage for significant inhalation of plutonium). 2. Electromagnetic radiation exposure. The patient is not radioactive and does not pose a contamination threat. There is no need for decontamination once the patient has been removed from the source of exposure, unless electromagnetic radiation emitter fragments are embedded in body tissues. /Radiation (Ionizing)/[Olson, K.R. (Ed.); Poisoning & Drug Overdose. 4th ed. Lange Medical Books/McGraw-Hill. New York, N.Y. 2004., p. 330] **PEER REVIEWED**

Therapeutic actions to prevent the uptake of strontium are based primarily on reducing GI tract absorption and accelerating the passage of material through the GI tract. These measures require administration under medical supervision ... . Aluminum phosphate gel and sodium alginate are the drugs identified as being potentially effective in reducing the GI tract uptake of strontium.[Pacific Northwest National Laboratory; HANFORD: Radiation and Health Technology Methods and Models of the Hanford Internal Dosimetry Program. PNNL-MA-860 (2003) Available from, as of October 4, 2006: http://www.pnl.gov/eshs/pub/pnnl860/pnnl860.pdf] **PEER REVIEWED**

If exposure to strontium-90 has occurred or is suspected to have occurred, one or more urine samples should be scheduled for investigation purposes. Because of the high sensitivity of the urine sample analysis, even slight intakes of strontium-90 resulting in small fractions of a millirem committed effective dose equivalent can be detected if prompt sampling is performed. This also permits the use of less sensitive analytical procedures (i.e., expedite or emergency processing analyses) for reasonably accurate dose estimates. In vivo measurements should also be considered following potential strontium-90 exposures ... . For relatively small intakes, fecal samples for strontium are not likely to be warranted because of the high degree of systemic uptake and the ease of detection by urine sampling. If major intakes are suspected, fecal samples combined with urine samples may provide more accurate estimates of intake, particularly if the intake is thought to contain some nontransportable strontium.[Pacific Northwest National Laboratory; HANFORD: Radiation and Health Technology Methods and Models of the Hanford Internal Dosimetry Program. PNNL-MA-860 (2003) Available from, as of October 4, 2006: http://www.pnl.gov/eshs/pub/pnnl860/pnnl860.pdf] **PEER REVIEWED**

Immediate First Aid/ Ensure that adequate decontamination has been carried out as needed. If patient is not breathing, start artificial respiration, preferably with a demand valve resuscitator, bag-valve-mask device, or pocket mask, as trained. Perform CPR if necessary. Immediately flush contaminated eyes with gently flowing water. Do not induce vomiting. If vomiting occurs, lean patient forward or place on left side (Head-down position, if possible) to maintain an open airway and prevent aspiration. Keep patient quiet and maintain normal body temperature. Obtain medical attention. /Radiological Threats: Radiological Dispersal Devices or Weapons/[Currance, P.L. Clements, B., Bronstein, A.C. (Eds).; Emergency Care For Hazardous Materials Exposure. 3Rd edition, Elsevier Mosby, St. Louis, MO 2005, p. 502] **PEER REVIEWED**

Basic Treatment. Establish a patent airway (oropharyngeal or nasopharyngeal airway, if needed). Watch for signs of respiratory insufficiency and assist ventilations if necessary. Administer oxygen by nonrebreather mask at 10 to 15 L/min. Monitor for shock and treat if necessary. Anticipate seizures and treat if necessary. Perform routine emergency care for associated injuries. For eye contamination, flush eyes immediately with water. Irrigate each eye continuously during transport. Do not use emetics. For ingestion, rinse mouth and administer 5 mL/kg up to 200 mL of water for dilution if the patient can swallow, has a good gag reflex, and does not drool. Perform routine BLS care as necessary. /Radiological Threats: Radiological Dispersal Devices or Weapons/[Currance, P.L. Clements, B., Bronstein, A.C. (Eds).; Emergency

Care For Hazardous Materials Exposure. 3Rd edition, Elsevier Mosby, St. Louis, MO 2005, p. 502] **PEER REVIEWED**

Special Considerations. Radiation monitors should be available to evaluate the radiation dose rates and compute/verify safe times to remain in contaminated areas. Experts are needed to review the data and provide specific recommendations to the Incident Commander as to the hazards present in the affected areas. Medical radiation experts should be available to guide patient treatment. Most symptoms from radioactive product exposure are delayed; treat other medical or trauma problems according to normal protocols. An accurate history of the exposure is essential to determine risk and proper treatment modalities. The dose of radiation determines the type and clinical course of exposure: 100 rads: GI symptoms (nausea, vomiting, abdominal cramps, diarrhea). Symptom onset within a few hours. 600 rads: Severe GI symptoms (Necrotic gastroenteritis) may result in dehydration and death within a few days. Several thousand rads: neurological/cardiovascular symptoms (confusion, lethargy, ataxia, seizures, coma, cardiovascular collapse) within minutes to hours. Bone marrow depression, leukopenia, and infections usually follow severe exposures. Assistance and advice on patient care concerns may be obtained from the Oak Ridge Radiation Emergency Assistance Center and Training Site 24 hours a day by calling (615) 576-3131 or (615) 481-1000, ext. 1502 or beeper 241. /Radiological Threats: Radiological Dispersal Devices or Weapons/[Currance, P.L. Clements, B., Bronstein, A.C. (Eds).; Emergency Care For Hazardous Materials Exposure. 3Rd edition, Elsevier Mosby, St. Louis, MO 2005, p. 503] **PEER REVIEWED**

Initial Emergency Department Considerations. Chelating agents or pharmacologic blocking drugs (potassium iodine, diethylenetriamine pentaacetic acid (DTPA), dimercaprol (British antilewisite, BAL), sodium bicarbonate, Prussian blue, calcium gluconate, ammonium chloride, barium sulfate, sodium alginate, D-penicillamine) may be useful if given before or immediately after exposure. The Oak Ridge number listed /in Special Considerations/ can be contacted for specific treatment advice. /Radiological Threats: Radiological Dispersal Devices or Weapons/[Currance, P.L. Clements, B., Bronstein, A.C. (Eds).; Emergency Care For Hazardous Materials Exposure. 3Rd edition, Elsevier Mosby, St. Louis, MO 2005, p. 503] **PEER REVIEWED**

ANIMAL TOXICITY STUDIES:

TOXICITY SUMMARY:

The beta-particle emitters strontium-90, yttrium-90 and 32-P-phosphate ... are bone-seeking radionuclides that attach to bone surfaces, from which they irradiate the marrow, and the depth of penetration of the radiation often exceeds that of similarly located alpha-particle emitters. Beta emissions from strontium-90 have a limited ability to penetrate through tissue. For that reason, radiostrontium must be internalized or placed in close contact with skin before adverse health effects will occur. The "bone-seeking" behavior of strontium is the basis for concern regarding oral or inhalation exposures to the radioactive isotopes, particularly strontium-90, with its long half-life of 29 years and highly energetic 0.546 MeV beta particles, plus the 2.2 MeV beta particles of its short-lived yttrium-90 decay product isotope. /Srontium-90, yttrium-90 and 32-P-phosphate/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 399, 477 (2001)] **PEER REVIEWED**

EVIDENCE FOR CARCINOGENICITY:

There is inadequate evidence in humans for the carcinogenicity of strontium-90. /Strontium-90/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 478 (2001)] **PEER REVIEWED**

There is sufficient evidence in experimental animals for the carcinogenicity of pure beta-particle emitters (hydrogen-3, phosphorus-32, strontium-90, yttrium-90, yttrium-91 and promethium-147). /Tritium, phosphorus-32, strontium-90, yttrium-91, promethium-147/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 478 (2001)] **PEER REVIEWED**

NON-HUMAN TOXICITY EXCERPTS:

/LABORATORY ANIMALS: Acute Exposure/ /CARDIOVASCULAR SYSTEM/ Acute inhalation of radiostrontium was reported to lead to adverse cardiovascular effects in dogs. Among beagles that died within 5-15 months following inhalation exposure to strontium-90 fused-clay particles, most exhibited myocardial necrosis or degeneration, and fibrosis, primarily of the right atrium; these animals had initial lung burdens between 33 and 100 uCi/kg (1.2-3.7 MBq/kg) and cumulative beta radiation doses to the lung of 34,000 to 82,000 rad (340-820 Gy). In a later report of the same study, acute and chronic vascular lesions, characterized as inflammatory or degenerative, affected the elastic and muscular pulmonary arteries in dogs with initial lung burdens between 16 and 94 uCi/kg (0.6-3.5 MBq/kg) and doses to the lung between 40,000 and 96,000 rad (400-960 Gy) at the time of death. Vascular damage in the lungs was characterized by congestion, hemorrhage, fibrin exudation, and occasional vessels with fibrinoid necrosis or intimal proliferation. These effects were attributed to the direct effect of beta radiation (from radiostrontium particles embedded in the lung) on adjacent tissue. In addition, presumably as a consequence of radiation damage to the pulmonary vasculature, the right ventricle became dilated and hypertrophic with congestive heart failure. Hemangiosarcomas /also resulted/ from radiostrontium exposure in this study ... /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium, p 70 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Acute Exposure/ /GASTROINTESTINAL SYSTEM/ Gastrointestinal effects were observed in beagle dogs receiving single high doses (long-term retained body burdens between 47 and 83 uCi/kg; 1.74 and 3.07 MBq/kg) of soluble aerosols containing 90-SrCl2. Anorexia and, 2 days before death, bloody diarrhea, developed in six dogs that died between 18 and 32 days after the extreme radiation dose rate induced acute radiation syndrome. It is likely that severe thrombopenia, one of the features of radiation-induced bone marrow hypoplasia, contributed to hemorrhage in the gastrointestinal tract as elsewhere in the body. In addition, some effects could have been due to inhaled 90-SrCl2 droplets being transported from the mucoid, ciliated nasopharyngeal and tracheobronchial epithelia to the pharynx and then swallowed. The gastrointestinal epithelium then would have been exposed directly to beta emissions from radiostrontium for a day or two. Another report of the same study described three exposed dogs that died at age > 11 years with a malabsorption syndrome. All of the dogs exhibited chronic diarrhea with anorexia, and at necropsy, contained chronic degenerative and inflammatory lesions of the small intestines. Their long-term retained burdens were 1.9 to 9.6 uCi/kg (70.3-355.2 kBq/kg) and the absorbed doses to the skeleton were calculated to be 530 to 5,600 rad (5.3-56 Gy). Although the authors could not firmly establish whether the syndrome was a consequence of exposure or of age, the cumulative radiation dose to the digestive tract was likely to have been very low and this argues against strontium-90 as the cause. /Strontium-90 chloride/[DHHS/ATSDR Toxicological Profile for Strontium, p 71-2 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Acute Exposure/ /SKIN/ Acute dermal reactions to strontium-90 have been described for depilated skin in mice, guinea pigs, and pigs. In mice, skin exposed to a single 2,000-5,000 rad (20-50 Gy) dose for beta radiation from a 90-Sr-90-Y source sustained an acute reaction. For example, all mice exposed once to 5,000 rad (50 Gy) from a 1 mm diameter source developed an acute skin reaction ... After an asymptomatic period of 2 or 4 days, the skin exhibited increasing erythema and pigmentation changes, leading to dry desquamation by day 10. WIthin a few days, exposed skin entered a period of moist desquamation, during which a serum scab was formed that was prevalent between days 15 and 25. Re-growth of the epithelium commenced at the edges of the irradiated field and from surviving hair follicles. By 1 month postirradiation, the epidermis was overtly normal, although histologically hyperplastic. Chronic fibrosis was a delayed skin reaction that was not apparent until 3 to 6 mo postirradiation. /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 106 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Subchronic or Prechronic Exposure/ /HEMATOPOIETIC SYSTEM/ Among young (30 days old) Long-Evans rats that were given > 300 uCi strontium-90/kg/day (11 MBq/kg/day) in drinking water for 10 days (total 460 uCi; 17 MBq), the bone marrow was extremely hypoplastic. Hypoplastic effects were slight among adult males given doses of 64 or 135 uCi/kg/day or adult females given 92 or 194 uCi/kg/day (total 330 or 650 uCi; total 12.2 or 24.1 MBq). Skeletal radiation doses were about 15 times higher in the younger rats. /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 91 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Subchronic or Prechronic Exposure/ /HEMATOPOIETIC SYSTEM/ In an intermediate-duration study in young Long-Evans rats, moderate hypoplasia of the bone marrow occurred among males (87 days old) given 74 uCi/kg/day and females given 104 uCi/kg/day (2.7 and 3.8 MBq/kg/day, respectively) of atrontium-90 in drinking water for 30 days (total 790 uCi; 29.2 MBq). Hypoplasia of the bone marrow leading to anemia and thrombocytopenia developed in Dutch rabbits that were fed approximately 6 uCi 90Sr/kg/day (218 kBq/kg/day) in pellets for 31-280 days. /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 89-90 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Subchronic or Prechronic Exposure/ /BONE/ In an acute uptake, chronic radiation study, male and female 30-day-old Long-Evans rats that were given 300 or 390 uCi strontium-90/kg/day, respectively (11 or 14.4 MBq/kg/day) in drinking water for 5-10 days (total 460 uCi; 17 MBq) exhibited signs of abnormal osteogenesis more than 10 months after administration. As marrow failed to invade into metaphyseal cartilage, the cartilage resumed active proliferation. Resorption failed to occur in metaphyseal cartilage and metaphyseal spongiosa failed to transform to lamellar bone. Often, cartilage and fibrous marrow were incorporated into cortical bone, sometimes causing fracture and deformation. /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 90-1 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Subchronic or Prechronic Exposure/ /BONE/ In an intermediate uptake, chronic radiation study on young (87 days old) Long-Evans rats, ingestion of 74 uCi (males) or 104 uCi (females) strontium-90/kg/day (2.7 or 3.8 MBq/kg/day) in drinking water for 30 days (total 790 uCi; 28.9 MBq) adversely affected the vasculature of the bone, which interfered with the normal transformation of cartilage into bone. At the end of the long bones, the cartilage discs were damaged, with detachment of primary spongiosa and failure of resorption. In another intermediate-duration study, numbers of osteocytes (bone cells surrounded by a mineralized matrix and connected by a mesh-work of processes) were reduced in Dutch rabbits that ingested approximately 6 uCi strontium-90/kg/day (218 kBq/kg/day) in pellets for 48 days.

/Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 91 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ /HEMATOPOIETIC SYSTEM/ Inhalation of aerosols containing strontium-90 chloride produced dose-related pancytopenia in dogs with a retained burden of > 0.37 MBq/kg bw. Thrombocytopenia and neutropenia were persistent until the death of the animals. The effects were reported to be similar to those seen after external irradiation. In rodents given 1 uCi (37 kBq)/g 32-P-phosphate per day for 14 days per month for three months, bone-marrow damage was inferred from decreases in the numbers of erythrocytes and lymphocytes and an increase in the fraction of circulating neutrophils and immature cells. /Strontium-90 chloride and phosphorous-32 phosphate/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 399 (2001)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ /LUNG/ Pneumonitis and fibrosis (as well as carcinogenesis) developed after inhalation of insoluble aerosols containing either strontium-90 /or/ yttrium-90/91and the sequential alterations in the function of the lungs /led/ to death from pulmonary failure. /Strontium-90 and yttrium-90/91/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 403 (2001)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ A series of experiments was reported on the effects of ip injected 90-Sr(NO3)2 in CBA mice. Groups of 120-122 male CBA mice, 75 days of age, were injected ... with a dose of 0.2, 0.4, 0.8, or 1.6 mCi/kg bw (7.4, 14.8, 29.6, or 59.2 MBq/kg bw). A group of 95 controls was available. Five mice per group were killed at one, two, three, and four weeks and at monthly intervals thereafter until all the mice had either died or been killed. Tumors of the bone, mucous membranes of the head, and hematopoietic system were found. The numbers of osteosarcomas were 0, 8, 90, 292, and 219 in controls and at the four doses, and the numbers of carcinomas of the hard palate, jaw, nose or sebaceous ear ducts were 0, 0, 3, 23, and 74, respectively. A total of 75 lymphatic or thymic lymphomas were reported in treated mice, the highest incidence occurring in mice injected with 0.4 mCi/kg bw (14.8 MBq/kg bw). /Strontium-90 nitrate/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 287 (2001)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ /In/... a lifetime study on the effects of strontium-90, ...groups of 12-14 pure-bred beagle dogs received a single iv injection of strontium-90 in a citric acid-sodium citrate buffer solution, and 13 control dogs received the buffer solution only. ...Twenty-four primary bone tumors occurred in 18 dogs: 18 were osteosarcomas, five were hemangiosarcomas, and one was of undetermined histological phenotype. These tumors all occurred at a median absorbed dose of beta-particles of 94 Gy (range, 18-164 Gy); none was seen in dogs that received doses to the skeleton of 0.7-18 Gy. In spite of substantial irradiation of the bone marrow, no myeloproliferative disease was observed. /Strontium-90 citrate/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 287-8 (2001)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ In response to concern about the possible long-term biological effects of strontium-90 in fallout from atmospheric nuclear weapons tests, a second lifespan study was conducted ... in which beagle dogs were exposed to strontium-90 in utero and up to 540 days of age. ... A total of 403 pure-bred beagle dogs (approximately equal numbers of males and females) were divided into seven groups receiving logarithmically spaced doses. The animals were derived from 125 dams fed strontium-90 from 40 days after breeding to 42 days after parturition when they weaned their pups. The pups received strontium-90 in the same 90-Sr:calcium ratio as the dams daily until they were 540 days of age. ... The median survival times at the four lower doses ranged from 13.5 to 14.4 years, while that for the 162 pooled controls was 14.4 years, and those at the three higher doses were 2.2 to 12 years. ... Primary sarcomas of bone were classified as osteosarcoma, chondrosarcoma, fibrosarcoma, hemangiosarcoma and undifferentiated sarcoma. In all, 66 primary bone sarcomas were found in 47 dogs, including four controls, multiple sarcomas being found in one female control, four males at the highest dose and 10 females at the two higher doses. All the bone sarcomas occurred at the four higher doses, and 74% of these tumors were osteosarcomas; the remainder was made up of other sarcoma types. The ratio of bone sarcomas of the appendicular skeleton to those of the axial skeleton was 38:23. /Strontium-90/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 288-90 (2001)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ In a third lifetime study of the biological effects of strontium-90 in dogs, 33 young adult (12-14 months) male and 33 female pure-bred beagle dogs were exposed once, briefly, to an aerosol of 90-SrCl2 in a cesium chloride vector aerosol, with activity median aerodynamic diameters of 1.4-2.7 um. ... Six dogs with retained burdens of 1.7-4.1 MBq/kg bw died 18-31 days after exposure from bone-marrow hypoplasia. Bone tumors were the main biological finding, 45 tumors occurring in 31 dogs, of which 24 were osteosarcomas, 14 were hemangiosarcomas, three were fibrosarcomas and one was a myxosarcoma. Four carcinomas of soft tissues near the bone in the nasal cavity and skull were found. Two cases of myelomonocytic leukemia were observed in dogs, with retained burdens of 1.0 and 0.35 MBq/kg bw. Three 90-Sr-related tumor deaths (one bone tumor, one nasal cavity tumor and one case of myelomonocytic leukemia) were found in 24 dogs with retained burdens of < 0.5 MBq/kg bw. /Strontium-90 chloride/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 290-2 (2001)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ /LUNG/ The only respiratory effects reported for the study in which beagle dogs were exposed to soluble aerosols of 90-SrCl2 were late primary cancers of the respiratory tract or tumors metastasizing to the lung. Respiratory effects were more pronounced in beagle dogs that were exposed to strontium-90 fused-clay particles by inhalation. The primary cause of early death among dogs exposed to initial lung burdens > /= 25 uCi strontium-90/kg (925 kBq/kg) was radiation pneumonitis and/or pulmonary fibrosis. No such effects were reported in control dogs exposed to nonradioactive aluminosilicate-fused clay particles. Clinical signs included an increased respiratory rate, dyspnea, cyanosis, and dry and moist rales. Radiographically, the dogs showed increased focal or diffuse lung-field densities. The pneumonitis was characterized by acute and chronic inflammation with increased numbers of alveolar macrophages, hypertrophy and hyperplasia of alveolar lining cells, degeneration of the bronchiolar epithelium and alveolar ducts, focal emphysema, and edema. The fibrosis involved the alveolar septa, pleura, and perivascular regions, with substantial scarring. Vascular damage in the lungs was characterized by congestion, hemorrhage (possibly related to thrombocytopenia), fibrin exudation, and occasional vessels with fibrinoid necrosis or intimal proliferation. /Strontium-90 chloride or fused clay/[DHHS/ATSDR; Toxicological Profile for Strontium p. 65, 70 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ /HEMATOPOIETIC SYSTEM/ Significant dose-related pancytopenia developed in dogs that were exposed to 90-SrCl2 aerosols and had long-term retained burdens > 10 uCi (370 kBq) strontium-90/kg. Profound decreases in platelet numbers were evident by 7 days and were maximal by 28 days. Drastic thrombocytopenia (platelets reduced > 90%) probably contributed to widespread hemorrhaging and premature death in dogs with long-term retained burdens > / = 47 uCi/kg (> / = 1.7 MBq/kg). Significant immediate reductions in platelet counts (> 60%) occurred in surviving dogs with long-term retained burdens of > / = 1.5 uCi/kg (> / = 0.56 MBq/kg). However, even dogs with the lowest long-term retained burdens (1-10 uCi/kg; 0.04-0.36 MBq/kg), which otherwise showed little immediate effect, exhibited long-term (> 3 years) depression in platelet counts compared to controls. The pattern of neutropenia followed a similar exposure-response, and profound neutropenia was the most accurate predictor of death. In surviving dogs that were immediately affected by exposure, neutrophil counts recovered, but in these dogs, as well as those immediately unaffected, significant long-term (> 3 years) suppression was observed compared to controls. Similarly, lymphocyte counts were drastically reduced (by 75%) in dogs dying within weeks of exposure with long-term retained burdens > / = to 47 uCi/kg (> / = 1.7 MBq/kg). Surviving dogs with long-term retained burdens > 10 uCi (370 kBq) strontium-90/kg exhibited a long-term (> 3 years) suppression of lymphocyte counts (> 30%). /Strontium-90 chloride/[DHHS/ATSDR Toxicological Profile for Strontium p 71-2 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ /LUNG/ Among 127 beagle dogs exposed by inhalation to strontium-90 fused-clay particles, deaths from primary pulmonary tumors were common: 19 dogs with hemangiosarcomas (one each also with bronchioalveolar carcinoma, nasal squamous cell carcinoma, or pulmonary epidermoid carcinoma), and one with pulmonary squamous cell carcinoma. All 34 dogs exposed to strontium-90 fused clay particles with cumulative exposures of > 29,000 rad (290 Gy) developed pulmonary hemangiosarcoma. The heart wall was the other primary location of hemangiosarcoma (11 dogs), the others being the mediastinum, spleen, rib, lung-associated lymph nodes, and liver. Hemangiosarcomas were metastatic in all but one affected dog. Among dogs dying prematurely from neoplasms of the lung, the initial lung burdens were 3.7-94 uCi/kg (0.14-3.5 MBq/kg) and the estimated cumulative doses to the lungs ranged from 43,000 to 67,000 rad (430-670 Gy). Considering all dogs with tumors, pulmonary carcinomas or sarcomas occurred in 3/12 dogs that received cumulative radiation doses of 17,000-25,000 rad (170-250 Gy), but no pulmonary tumors were reported for three dogs with cumulative exposure levels of 11,000-15,000 rad (110-150 Gy). /Strontium-90 fused clay/[DHHS/ATSDR Toxicological Profile for Strontium, p 75-6 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ /HEMATOPOIETIC SYSTEM/ Chronic-duration studies in several species reported suppression of hematopoiesis. In albino rats fed 0.5 uCi strontium-90/kg/day (18.5 kBq/kg/day) for their post-weaning lifetime, hematopoiesis was significantly depressed. Lymphocytes were the first cells affected, then neutrophils, thrombocytes, and after 1 year, erythrocytes. Morphological abnormalities included binucleation. At 0.5 uCi 90-Sr/kg/day (18.5 kBq/kg/day), leukocyte numbers remained 20% depressed by the end of the second year. The authors calculated that the minimal dose to induce leukopenia was 150-200 rad. The reduction in leukocytes plateaued at about

30-35% for absorbed doses between 400 and 2,000 rad. Hematological effects were reported in a chronic-duration beagle study, in which animals were exposed to 0.002-1.2 uCi/kg/day (0.074-44.4 kBq/kg/day) of strontium-90 in utero from gestational day 21, throughout lactation, and from weaning on day 42 to day 540. Six years after exposure began, the following effects were observed ... abnormal erythrocyte morphology (primarily poikilocytosis, anisocytosis, and hypochromasia, with some instances of macrocytosis), dose-related, radiation-induced leukopenia, an abnormal number of immature granulocytes, one case of unusual giant neutophils, a reduction in the number of platelets, anemia, and splenomegaly. Similarly, female Pitman-Moore miniature swine exposed to 3,100 uCi strontium-90/day (114.7 MBq/day) as strontium chloride died within 3-4 months from destruction of hematopoietic tissue in bone marrow, which resulted in anemia, leukopenia, thrombocytopenia, and terminal hemorrhagic syndrome. In addition, two animals in this group developed myeloid metaplasia. /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 90 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ /BONE/ Bone damage was a notable effect of chronic-duration oral exposure to radioactive strontium in dogs. Groups of pregnant beagles were fed 0.002-3.6 uCi strontium-90/kg/day (0.074-133.2 kBq/kg/day) from gestational day 21 through lactation to PND 44, and the pups were fed the same doses from weaning at day 42 through day 540. Ten years from the start of the study, dose-related skeletal effects included mild trabecular osteopenia, endosteal and periosteal cortical changes (sclerosis and thickening), and mottling or focal osteolytic lesions. These occurred in all the dogs in the 3.6 uCi/kg/day group and also in the 1.2 and 0.4 uCi/kg/day groups (133.2, 44.4, and 14.8 kBq/kg/day, respectively). Radiation-induced osteodystrophy was noted in three out of four beagle dogs that received 1.2 uCi strontium-90/kg/day (44.4 kBq/kg/day) for life beginning at midgestion; the average dose rate (cumulative dose divided by lifespan) for these dogs was 4 rad/day (0.04 Gy/day). Radiation osteonecrosis was said to be a common finding among female Pitman-Moore miniature swine that died with hematopoietic disorders or bone marrow hypoplasia after ingesting 90-SrCl2 at levels between 1 and 3,100 uCi/day (0.37-114.7 MBq/day) until death. The incidence of osteonecrosis at each dose level was not reported. Bone cancers ... were /also/ reported in these chronic studies. /Strontium-90/[DHHS/ATSDR Toxicological PRofile for Strontium p 91 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ Relatively large studies in rats and/ mice...demonstrated increased tumor induction following chronic ingestion of strontium-90. In the rat study, albino rats were fed between 0.05 and 2 uCi 90-Sr/kg/day for their post-weaning lifetime, resulting in exposures between 0.01 and 0.4 uCi/day. In rats consuming 2 uCi 90-Sr/kg/day, the number of rats with malignant tumors was 18.7%, compared to 1.3% for controls. At 0.5 90-Sr/kg/day, the tumor incidence was 3-6 times lower (not specified numerically), but the outcome at 0.05 90-Sr/kg/day was not reported. The most common malignancies were lymphosarcoma (8%), osteosarcoma (6.7%), and leukosis (4%). The latency periods were 300-540 days for lymphosarcomas and 450-660 days for "leukosis" and osteosarcoma. The cumulative absorbed doses averaged 1,350 rad (13.5 Gy) just before the onset of lymphosarcoma, 2,200 rad (22 Gy) just before the onset of leukosis, and 2,400 rad (24 Gy) just before the onset of osteosarcoma. In the mouse study, mice were exposed either as adults (beginning at age 110-250 days) or from conception to 0.05-36 uCi 90-Sr/kg/day. There was a higher incidence of reticular tumors in blood-forming tissues, but no evidence of osteogenic sarcoma in all adult exposed groups. ... However, the tumor incidence was significantly elevated in mice exposed to strontium-90 from conception. The highest dose level resulted in the early appearance of reticular tumors, especially lymphomas; 24% of mice at this level died with reticular-tissue tumors by 525 days, compared to 6% in controls. Other tumors unique to the high-dose level included six osteogenic sarcomas, four osteolytic tumors, and two epidermoid carcinomas of the oral cavity. Radiography demonstrated that radioactive strontium was ubiquitously distributed throughout the skeleton of mice exposed from conception. I /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 99-100 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ Relatively large studies in ... dogs ... demonstrated increased tumor induction following chronic ingestion of strontium-90. In the dog study, groups of pregnant beagles were fed between 0.002 and 3.6 uCi 90-Sr/kg/day (0.074 and 133.2 kBq/kg/day) from day 21 of gestation to postnatal day 42. The pups were weaned and then fed a diet containing the same 90-Sr/calcium ratio as the dam until day 540. Bone sarcoma deaths occurred in dogs ingesting between 0.13 and 3.6 uCi 90-Sr/kg/day (4.8-133.2 kBq/kg/day) resulting in bone doses at death of 5,000-10,700 rad (50-107 Gy), but not at 0.002-0.043 uCi 90Sr/kg/day (0.1-1.6 kBq/kg/day) with doses to death of 100-2,300 rad (1-23 Gy). The higher the amount of strontium-90 given, the earlier the age of onset of sarcomas and the more likely they were to be osteosarcomas. Of 66 sarcomas, 75% were osteosarcomas; other types were chondrosarcoma, hemangiosarcoma, fibrosarcoma, and undifferentiated sarcoma. Multiple tumors occurred only at the two highest doses. Other cancer deaths occurred at high doses: radiation-induced myeloid leukemia (43 deaths), oral or nasal carcinoma (29 deaths), and periodontal carcinoma (16 deaths). The leukemic animals (average age at death 1,156 days) were not at risk for osteosarcoma, which had an average age of onset of 2,864 days. /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 99-100 (2004)] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ /SKIN/ ... The carcinogenicity of strontium-90 beta irradiation to the skin of Swiss mice applied twice weekly ... /gave/ skin tumor incidences after 30 months /that/ were 12.3%... /Strontium-90/[United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes: Sources and Effects of Ionizing Radiation, Vol 2: Effects, p.245.] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ ... Data have been reported for osteosarcoma induction by strontium-90 in female CF1 mice. In groups of about 100 animals with average bone doses ranging from 0.26 to 120 Gy, no significant increase in tumor incidence was found in animals with average doses below about 10 Gy (1.3, 4.5, and 8.9 Gy). /Strontium-90/[United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes: Sources and Effects of Ionizing Radiation, Vol 2: Effects, p.100.] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ In beagle dogs with average skeletal doses from strontium-90 at 1 year before death of between 0.27 Gy and 111 Gy, no tumors were found in the three lowest dose groups (1, 3.35, and 5.97 Gy), with an 8% incidence occurring at 21.7 Gy. The numbers of dogs in each group was, however, only about 12, and a small increase in incidence could not have been detected. /Strontium-90/[United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes: Sources and Effects of Ionizing Radiation, Vol 2: Effects, p.100.] **PEER REVIEWED**

/LABORATORY ANIMALS: Developmental or Reproductive Toxicity/ Groups of five to eight CBA mice were given an iv injection of strontium-90 as the nitrate at a dose of 46.3, 92.5, 185, 370, or 740 kBq on day 19 of gestation. ... The female offspring (15-26 per group) ... were bred for seven months. The mice were killed at an average age of 10 months ... . The ovaries of mice at the higher doses were severely depleted of follicles and oocytes, but multiple corpora lutea were seen at lower doses. Interstitial fibrosis and cysts were the primary findings at the lower doses, and the incidence reached a maximum of about 50% at 185 kBq. Hyperplasia of interstitial cells and down-growth of the germinal epithelium into the ovarian parenchyma was seen at this dose and above. Ovarian tubular adenomas were found in 1/19, 5/10, and 12/21 mice treated with 185, 370, and 740 kBq, respectively. /Strontium-90 nitrate/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 321-2 (2001)] **PEER REVIEWED**

/LABORATORY ANIMALS: Developmental or Reproductive Toxicity/ Strontium-90 as the nitrate was injected iv into 12-week-old Wistar rats on day 18 of gestation. One group of 13 dams was injected with 100 uCi (3,700 kBq), 11 dams with 150 uCi (5,555 kBq) and another 24 dams received sterile saline. The offspring (60 males and 60 females and 53 males and 47 females in the two treated groups, and 111 male and 113 female controls) were necropsied at death or at 30 months of age and examined histologically. ... Pituitary tumors (chromophobe adenomas) were detected at necropsy in exposed animals as young as 15 months of age, but were found in the saline-injected controls only after 22 months. Among animals killed at 30 months, the incidence of pituitary tumors in exposed male offspring (about 30%) was about 10-fold that in controls (2.7%), and the rate in females (46-50%) was about three times higher than that in controls (15.9%). A dose-related increase in the incidence of mammary hyperplasia was found in exposed female offspring ... . About 9% of the male controls had lymphatic tumors of the thymus; this incidence rose to 16% at 100 uCi but was the same as in controls at 150 uCi. The incidence was increased to 55% and 50% in the two exposed groups of females compared with 35% in controls. The authors indicated that about 30% of the thymomas were of a preponderantly epitheloid cell type, where the lymphocytes often only seemed to be dispersed within the epitheloid cell bonds'and that this special type of thymoma was usually observed with a pituitary tumor. Metastatic meningeal sarcomas were detected in 11and 10 offspring from the two exposed groups (5.8 and 7.0%) but not in the controls. /Strontium-90 nitrate/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 322 (2001)] **PEER REVIEWED**

/LABORATORY ANIMALS: Developmental or Reproductive Toxicity/ ... Five to 110 uCi /of strontium-90 were injected/ ip into pregnant mice at various times during pregnancy and ... an increase in skeletal defects /was found/. /Strontium-90/[Shepard, T.H. Catalog of Teratogenic Agents. 5th ed. Baltimore, MD: The Johns Hopkins University Press, 1986., p. 527] **PEER REVIEWED**

/LABORATORY ANIMALS: Developmental or Reproductive Toxicity/ / ... Pregnant mice /were injected/ on 11th or 16th gestational day with 20 uCi of strontium-90. A general reduction of fetal oocytes was found. /Strontium-90/[Shepard, T.H. Catalog of Teratogenic Agents. 5th ed. Baltimore, MD: The Johns Hopkins University Press, 1986., p. 527] **PEER REVIEWED**

/LABORATORY ANIMALS: Developmental or Reproductive Toxicity/ About 800 Pitman-Moore miniature pigs representing three generations were fed strontium-90 at doses ranging from 0.037 to 115 MBq/day. Animals in the first generation were exposed from nine months of age, and those of the second and third generations were exposed in utero, during lactation, and in their feed after weaning at a dose that was initially one-fourth that of the sow and was increased by six months to the same as that of the sow. ... Bone sarcomas were observed /in females in the F1 and F2 generations/ only at the two higher doses. Most of the tumors occurred in the skull, including the mandible and maxilla. An increased incidence of hepatic neoplasia was seen at moderate doses, but only two of these tumors were malignant. Hematopoietic effects of irradiation of the bone marrow, including neutropenia, lymphopenia, thrombocytopenia and myeloproliferative disorders and histiocytic infiltration of organs such as the kidney, heart, testis, and lung were observed among animals at the higher doses but not in controls or pigs at lower doses and rates. /Strontium-90/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 292 (2001)] **PEER REVIEWED**

/GENOTOXICITY/ The objective of the present study was to evaluate the genotoxic and cytotoxic effects of strontium-90/yttrium-90 --a pure, highly energetic beta source-on Chinese hamster ovary (CHO) cells and to compare them with data obtained with cobalt-60. CHO cells irradiated with different doses of cobalt-60 (0.34 Gy/min) and 90-Sr/90-Y (0.23 Gy/min were processed for analysis of clonogenic death, induction of micronuclei (MN) and interphase death. The survival curves obtained for both types of radiation were fitted by the exponential quadratic model and were found to be similar. Also, the cytogenetic results showed similar frequencies of radio-induced MN between gamma and beta radiations ... . The irradiated cells showed more necrotic cells 72 hr and 96 hr after exposure to beta than to gamma radiation. In general, the 90-Sr/90-Y beta-radiation was more damaging than cobalt-60 gamma-rays. /Strontium-90/yttrium-90 and cobalt-60/[Murakami D et al; Radiat Environ Biophys 43 (2): 91-9 (2004)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=retrieve&db=pubmed&list_uids=15138771&dopt=AbstractPlus" target=new>PubMed Abstract

/OTHER TOXICITY INFORMATION/ Radium-228 treated beagles exhibited the highest number of radiation induced fractures and the most generalized distribution of fracture sites. The fracture pattern for radium-226 was similar except for a significantly lower incidence in the weight bearing (appendicular) skeleton. Plutonium-239 was characterized by a high percentage of costochondral rib fractures and a very low incidence in the appendicular skeleton. Strontium-90 seldom produced fractures. The healing response was lowest for radium-228, intermediate for plutonium-239 and highest for radium-226. /Strontium-90, plutonium-239, and radium-228/[Taylor GN et al; Hlth Phys 12 (3): 361-7 (1966)] **PEER REVIEWED**

/OTHER TOXICITY INFORMATION/ /SKIN/ Experimental studies on pig and mouse skin show that the effects produced are dependent on the range of the radiation emission, the area of skin irradiated, the thickness of skin, and the degree of skin penetration achieved by the radionuclide. For example, application of sources of strontium-90, technicium-170 and promethium-147 (high-, medium- and low-energy beta-particle emitters, respectively) to the skin of pigs (thick) or mice (thin) in vivo resulted in a range of deterministic effects, varying from slight breakdown of the most superficial layers of the epidermis, produced by high doses from promethium-147, to extensive local damage and moist desquamation, produced at about 28 Gy from large-area strontium-90 sources (22.5 mm in diameter). To produce the same effect with thulium, 80 Gy of beta-radiation from this radionuclide were required. The thresholds for acute tissue breakdown due to the larger-diameter sources of beta-radiation were 17 Gy for 90-Sr/90-Y and 30 Gy for thulium-170. In contrast, the threshold for less serious epidermal necrosis after irradiation by promethium-147 was 150 Gy. This is important, since exposure of 50% or more of the total body surface led to death of Chernobyl liquidators due to skin desquamation and subsequent infection when the doses to the skin exceeded 30 Gy for penetrating beta radiation and 200-300 Gy for less energetic emitters. /Strontium-90, technicium-170, promethium-147, and thulium-170/[IARC. Monographs on the

Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 394 (2001)] **PEER REVIEWED**

/OTHER TOXICITY INFORMATION/ /BONE/ The lowest average skeletal doses /in dogs/ that produced significant vascular depletion were reported to be 23 Gy for radium-226, 3.5 Gy for plutonium-239, 5 Gy for radium-228, and 2.5 Gy for thorium-238. In contrast, vascular effects were not seen up to a dose of 80 Gy in dogs injected with the beta-particle emitter strontium-90. The differences in the toxicity of these radionuclides is a consequence of their different deposition patterns or those of their progeny and, hence, dose distribution within the skeleton, and of the lower toxicity of beta-particle-emitting isotopes. /Radium-226, plutonium-239, radium-228, thorium-238, strontium-90/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 391 (2001)] **PEER REVIEWED**

/OTHER TOXICITY INFORMATION/ /Age related cancers/ In a study of the effects of age and dose on the carcinogenicity of strontium-90, groups of 47-51 female CBA mice were injected ip with 90-Sr(NO3)2 at a dose of 0.2, 0.4, or 0.8 mCi/kg bw [7.4, 14.8, or 29.6 MBq/kg bw] at 25, 75, 150, or 300 days of age. Higher incidences of osteosarcomas were seen in mice injected at 75 days of age, but no age-related effect was seen in the incidence of lymphatic tumors, which occurred more frequently at the low dose. /Strontium-90 nitrate/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 287 (2001)] **PEER REVIEWED**

/OTHER TOXICITY INFORMATION/ /Age-related bone cancer/ Acute-duration experiments using Long-Evans rats demonstrated that weanlings, with their relatively higher rate of incorporation of strontium into the skeleton, were more vulnerable than adults to the carcinogenetic effects of strontium-90. Weanlings (30 days old) were given 46 uCi strontium-90/day (1.7 MBq/day) and adults were given 33 or 65 uCi strontium-90/day (1.2 or 2.4 MBq/day) in drinking water for 10 days; on a body weight basis, the amounts given were > 300 uCi/kg/day (11 MBq/kg/day) for weanlings, 64 or 135 uCi/kg/day for adult males, or 92 or 194 uCi/kg/day for adult females. After 5 months, 33 uCi (1.2 MBq) of radioisotope were detected in the skeletons of weanlings that received 460 uCi (17 MBq), but only 1 or 2 uCi (37 or 74 kBq) were detected in the skeletons of adults that received 330 or 650 uCi (12.2 or 24.1 MBq), respectively. The differences in incorporation of strontium-90 probably accounted for the age-related differences in the incidence of osteosarcoma; 17.5% of weanlings developed osteosarcoma compared to none of the adults. However, in the high dose adults, the overall incidence of malignancy (leukemia, squamous cell carcinoma of the skin, various other carcinomas) was more than doubled, compared to controls. /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 98 (2004)] **PEER REVIEWED**

/OTHER TOXICITY INFORMATION/ /Reduced survival/ In experiments in which weanling (30 days old) and adult Long-Evans rats were given strontium-90 in drinking water for 10 days, survival at 5 months was reduced by 80% in the weanlings consuming at least 297-386 uCi strontium-90r/kg/day (11 MBq/kg/day; total 464 uCi or 17 MBq), but was unaffected in adults consuming 64-194 uCi strontium-90r/kg/day (7.2 MBq/kg/day; total 650 uCi or 24.1 MBq). The reduced survival of the weanlings was consistent with their higher skeletal burden at 5 months: > 20 times higher than in the adults. In another acute study, six young female dairy cattle (three sets of twins from three different strains, ages 398 and 479 days and weighing

145-349 kg at the start of treatment) were given 44 uCi strontium-90/kg/day (1.63 MBq/kg/day) orally'for 5 days. The four youngest (398 days) and lightest heifers (145-212 kg), which were administered a total of 32-46 mCi (1.18-1.70 GBq), died of radiation sickness between 93 and 132 days after treatment was started, whereas the older and heavier animals (342-349 kg), which had received a total of 75-77 mCi of strontium-90 (2.78-2.85 GBq), were still alive 3 years after treatment. In addition to age-related differences, strain differences may have contributed to the results; the older cows were Holsteins, which have more massive skeletons than the Brown Swiss and Jersey strains. The authors suggested that the larger animals survived because of the wider diameter of the marrow cavity, which possibly shielded the central marrow from beta radiation released from strontium-90 (and its 90-Y decay product) deposited at the periphery of the bone shaft. /Strontium-90/[DHHS/ATSDR Toxicological Profile for Strontium p 77-8 (2004)] **PEER REVIEWED**

ECOTOXICITY EXCERPTS:

/BIRDS AND MAMMALS/ Bank voles (Clethrionomys glareolus) and laboratory strains of house mice (Mus musculus BALB and C57BL) were relocated into enclosures in a highly contaminated area of the Red Forest near the Chornobyl (Ukraine) Reactor 4 to evaluate the uptake rates of cesium-137 and strontium-90 from abiotic sources. Mice were provided with uncontaminated food supplies, ensuring that uptake of radionuclides was through soil ingestion, inhalation, or water. Mice were sampled before introduction and were reanalyzed every 10 d for cesium-137 uptake. Levels of strontium-90 were assessed in subsamples from the native populations and in experimental animals at the termination of the study. Uptake rates in house mice were greater than those in voles for both cesium-137 and strontium-90. Daily uptake rates in house mice were estimated at 2.72x10+12 unstable atoms per gram (whole body) for cesium-137 and 4.04x10+10 unstable atoms per gram for strontium-90. Comparable rates in voles were 2.26x10+11 unstable atoms per gram for cesium-137 and 1.94x10+10 unstable atoms per gram for strontium-90. By comparing values from voles in the enclosures to those from wild voles caught within 50 m of the enclosures, it was estimated that only 8.5% of cesium-137 was incorporated from abiotic sources, leaving 91.5% being incorporated by uptake from biotic materials. The fraction of strontium-90 uptake from abiotic sources was at least 66.7% (and was probably much higher). Accumulated whole-body doses during the enclosure periods were estimated as 174 mGy from intramuscular cesium-137 and 68 mGy by skeletal strontium-90 in house mice over 40 d and 98 mGy from cesium-137 and 19 mGy from strontium-90 in voles over 30 d. Thus, uptake of radionuclides from abiotic materials in the Red Forest at Chornobyl is an important source of internal contamination. /Strontium-90 and cesium-137/[Chesser RK et al; Environ Toxicol Chem 20 (9): 1927-35 (2001)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11521818" target=new>PubMed Abstract

/AQUATIC SPECIES/ Turtles inhabiting a radioactive reservoir appear to experience genetic damage due to environmental exposure to low concentrations of long-lived radionuclides. Total body burdens for the 50 reservoir turtles examined in the survey ranged from 164.7-4679.3 Bq for cesium-137 and from 462.6-5098.3 Bq for strontium-90. Flow cytometric (FCM) assays of red blood cell nuclei demonstrated significantly greater variation in DNA content for the reservoir turtles than for turtles from a nearby, non-radioactive site. Furthermore, two of the reservoir turtles possessed FCM profiles that are indicative of aneuploid mosaicism. These data strongly suggest that exposure to low-level radiation may involve a sensitive genetic response in a natural population.[Lamb T et al; Arch Environ Contam Toxicol 20 (1): 138-42 (1991)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=1996906" target=new>PubMed Abstract

/OTHER TERRESTRIAL SPECIES/ Adults of the geotrupine beetle Anoplotrupes stercorosus (Coleoptera, Geotrupidae), a common European forest insect species, were used in the role of bio-monitors for mainly man-made radionuclides in a forest environment. Activities of cesium-137, potassium-40, plutonium-238, plutonium(239+240), strontium-90 and americium-241 were studied. Samples originated from four areas in Poland, two from the north-east and two from the south of the country. The north-eastern areas were previously recognized as the places where hot particle fallout from Chernobyl took place. Results confirmed the differences in the activities between north-eastern and southern locations. Significant correlations were found between activities of 40-K and 137-Cs, and between activities of plutonium and americium isotopes. An additional study of the concentration of radionuclides within the bodies of beetles showed a general pattern of distribution of radioisotopes in the insect body. /Cesium-137, potassium-40, plutonium-238, plutonium(239+240), strontium-90 and americium-241/[Mietelski JW et al; J Environ Monit 5 (2): 296-301 (2003)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids==12729271" target=new>PubMed Abstract

/FIELD STUDIES/ Carcasses of jackrabbits and kangaroo rats (Dipodomys spp.) were analyzed for strontium-90 after a fallout event from nuclear testing in Nevada. One year after the contamination event, jackrabbits had about twice the strontium-90 activity detected in rabbits collected another year later. It was suggested that bioavailability of strontium-90 was highest within a year of a nuclear test contamination event.[Shore R.F., Rattner BA. Ecotoxicology of Wild Mammals. Ecological & Environmental Toxicology Series 2001. John Wiley & Sons, New York, N.Y. 2001, p. 289] **PEER REVIEWED**

/FIELD STUDIES/ The research was conducted on rodents from territories of the East Ural radioactive trace. The strontium-90 activity of ground was 2 Ci/km2, 500 Ci/km2, 800 Ci/km2 (experimental plots) and on control territory --0.2 Ci/km2. In the liver of animals living on the polluted territories the activation of catalase and glutathionreductase, the increase in antioxidative activity and appropriate reduction of lipid peroxidation processes were observed. For 40 years after /the/ Kyshtym accident (70-100 generations of animals) an adaptive reaction has formed. /Strontium-90/[Ustinova AA et al; Radiat Biol Radioecol 43 (4): 420-3 (2003)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=14608673" target=new>PubMed Abstract

/FIELD STUDIES/ ... a cytophysiological analysis of testis in Clethrionomus rutilus /ruddy vole/ and Apodemus sylvaticus /common wood mouse/ inhabiting a contaminated area of the East Ural Radioactive Trace (EURT) /was made/. The study showed that in the norm these species differed in the total number of cells of spermatogenous epithelium, due to interspecific difference. In the sampling plot a concentration of strontium-90 in Clethrionomus rutilus was 2 times higher than that in Apodemus sylvaticus. Maximum destructive changes in endocrine and exocrine (seminiferous tubules) section of testis and increased proliferation activity of spermatogenous epithelium were observed in Clethrionomus rutilus.Increased proliferation activity was found as a compensatory-protective reaction which promote the maintenance of the germ cell number. Such changes were not observed in Apodemus sylvaticus.[Mamina VP; Radiats Biol Radioecol 45 (1): 91-5 (2005)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=15810529" target=new>PubMed Abstract

METABOLISM/PHARMACOKINETICS:

ABSORPTION, DISTRIBUTION & EXCRETION:

Inhalation: Measurements following accidental inhalation of strontium carbonate (90-SrCO3) by humans showed high solubility. Similarly, experiments in animals have shown that strontium in simple ionic compounds (chloride and sulfate) is cleared rapidly from the lungs, consistent with high solubility. A study in vitro on strontium-containing airborne fission products released during the Three Mile Island reactor accident confirmed these results. /Strontium carbonate/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 337 (2001)] **PEER REVIEWED**

Absorption of elements in the human lung after inhalation: Strontium, most soluble compounds, fast, 10 min (100%) /from table/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 41 (2001)] **PEER REVIEWED**

Because of the soluble nature of the strontium-90 ... , the distribution and retention patterns of strontium-90 /in beagle dogs/ after inhalation can be compared with those after iv injection. Minor differences were found. After injection, there was rapid deposition in the skeleton, which decreased with time due to biological processes, whereas exposure by ingestion led to continuous deposition of strontium-90 in the skeleton up to 540 days of age and a more uniform distribution within the bones. /Strontium-90/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 292 (2001)] **PEER REVIEWED**

Ingestion: Owing to the presence of strontium isotopes in fall-out material and its long-term retention in bone as a calcium analogue, the metabolism of strontium has been the subject of a number of studies in volunteers. Similar absorption values were obtained in studies in which inorganic forms of radiostrontium were administered orally in solution and in experiments in which known quantities of radiostrontium incorporated in food were ingested. The mean values were between 0.15 and 0.45. In a study of the absorption of strontium from real and simulated fall-out and after administration of 85-SrCl2, 10 volunteers ingested samples of local fall-out, largely comprising silicaceous soil constituents (40-700 um particles). The estimated absorption rate was 3%, with a range of 0 to 9%, while that for simulated fall-out prepared as glass microspheres (30-40 um) was 16% (range, 6-25%), with a value of 17% (8-34%) after administration as 85-SrCl2. /Strontium-85 chloride/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 338 (2001)] **PEER REVIEWED**

There is little evidence for systemic toxicity following dermal exposure to strontium compounds, which would suggest that they are not readily absorbed across the skin of humans. ... Three groups of three male volunteers received topical applications of strontium-85 as strontium chloride in aqueous solution (pH 7.0) without a carrier. In the first group, intact forearm skin (average area 8 sq cm) was exposed for 6 hours. In the second and third groups, the skin of the forearm was abraded with a metal grater just before the solution was applied; exposures were 6.1 sq cm for 30 minutes and 6.9 sq cm for 6 hours, respectively. For comparison, a fourth group received an intravenous injection of 85-SrCl2. After exposure and decontamination of the skin, radioactivity measurements were taken over 40 days of the strontium-85 present in the whole body, the patella, the right unexposed forearm, and, during the first 20 days, in daily urine samples. Absorption of strontium was estimated from whole body or partial body strontium-85 burdens, or urinary excretion of strontium-85 in comparison to the same end points after an intravenous dose of 85-SrCl2. The absorption of radiostrontium through intact skin over 6 hours was estimated to be 0.26% (range, 0.14-0.37%) of the applied dose, indicating that undamaged skin is a relatively effective barrier to penetration by strontium. Strontium absorption was greater through scratched and abraded skin. An average of 38% (range, 25.5-45.8%) of the applied dose was absorbed after 30 minutes and an average of 57.4% (range of coefficients, 55.7-65.3%) was absorbed after 6 hours. /Strontium-85 chloride/[DHHS/ATSDR Toxicological Profile for Strontium p 123-4 (2004)] **PEER REVIEWED**

Radium and strontium, which are alkaline earth elements, follow the metabolic pathways of calcium and are deposited almost exclusively in the skeleton. Therefore, the radionuclides of these elements are likely to substantially irradiate only skeletal tissues. /Radioactive radium and strontium/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 389 (2001)] **PEER REVIEWED**

Biodistribution of elements in human adults: Strontium, Principal deposition sites, skeleton (25 % entering blood); Retention half-time > or = 20 years /from table/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 65 (2001)] **PEER REVIEWED**

The results of measurements of the absorption of strontium in seven-day-old infants fed cows milk suggested values > 73%. Similar levels of absorption have been reported for 5 to 15-year-old children and adults. However, studies in beagles and rats have shown that the period of increased absorption of strontium extends beyond the time of weaning. In beagles, the retention values for strontium 3-9 days after ingestion were 20%, 15%, and 8% in 48-, 80-, and 140-day-old animals, respectively. The absorption of strontium was estimated to be 70-90% in 35- and 75-day-old rats and 12% in 270-day-old rats. /Radioactive strontium/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 338 (2001)] **PEER REVIEWED**

Systemic distribution, retention and excretion: The behavior of strontium in the body is similar to that of calcium, but there are quantitative differences that reflect discrimination against strontium and result in less effective incorporation and retention in bone and more rapid urinary excretion. Long term retention of strontium, like that of calcium, is confined to the skeleton, and doses from strontium-90 absorbed into blood are delivered largely to bone surfaces and red bone marrow. /Strontium-90/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 338 (2001)] **PEER REVIEWED**

Systemic distribution, retention and excretion: Measurements in human bone of strontium-90 from fall-out and information on dietary intake ...

indicate that strontium is less efficiently retained in bone than calcium, consistent with discrimination against inclusion of strontium in hydroxyapatite crystals. /Strontium-90/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 339 (2001)] **PEER REVIEWED**

Systemic distribution, retention and excretion: There is considerable evidence in humans and laboratory animals that the initial uptake of strontium and calcium by the skeleton is much greater in growing than in mature individuals. The available data are consistent with changes in the rate of addition of calcium to the skeleton with age. Bone turnover is also greater at younger ages. /Strontium, NOS/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 339 (2001)] **PEER REVIEWED**

High resorption rates of radiostrontium were certified by data obtained ... from experiments conducted in monkeys (macaques) who had a solution of strontium chloride (85-SrCl2) injected im or topically applied to the lacerated femoral wound. Just 40 min after the administration, 100% of radionuclide had been resorbed from the stab wound and the maximum blood concentration of strontium-85 was observed at minute 20. When radionuclide was applied to the lacerated wound, 22 and 37% of the administered amount was resorbed in the body at minutes 15 and 100, respectively, which is predetermined by the morphological peculiarities of lacerated wounds. /Strontium-85 chloride/[Gusev, I.A., Guskova, A.K., Mettler, F.A. (eds) Medical Management of Radiation Accidents. Second Edition. CRC Press. Boca Raton, FL. 2001, p. 369] **PEER REVIEWED**

Placental transfer: Studies of human tissues and animals in which direct comparisons have been made show that strontium is transferred to the fetus less efficiently than calcium. The available data suggest a placental discrimination factor in humans of about 0.6. /Strontium, NOS/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 339 (2001)] **PEER REVIEWED**

Placental transfer: The concentrations of strontium-90 were measured in six stillborn fetuses and their mothers who had drunk water from the Techa River at various times before pregnancy. The skeletal concentration ratios (fetus:mother) were 0.01-0.03 when maximum intake of 90-Sr had occurred largely during the childhood of the mother (< 15 years) and 0.19-0.24 when maximum intake had taken place during adulthood (> 25 years). /Strontium-90/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 339 (2001)] **PEER REVIEWED**

Placental transfer: 85-SrCl2 was administered ip to rats at a dose of 20 kBq/kg bw one month before conception or on day 2, 13, or 19 of gestation. Neonates retained an average 0.002%, 0.03%, 0.1%, and 3% of the injected activity, respectively, corresponding to fetal:dam concentration ratios of 0.03, 0.06, 0.2, and 5. /Strontium-85 chloride/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 339 (2001)] **PEER REVIEWED**

The retention in suckling young of strontiium-90 accumulated during late fetal life and during the period of nursing following a single maternal injection was measured in rats. Rat dams of the Long-Evans strain were injected intravenously with 379 uCi of strontium-90 on day 17 post-conception. Bremsstrahlung measurements based upon 65 offspring showed that a body burden of 1.49 uCi per offspring was contained at birth. At least 1.19 uCi in excess of the body burden at parturition was accumulated from the milk by day 14 post birth. Fractional retention of strontium-90 in the offspring between 40 and 300 days post-weaning was described by the equation R = 0.006 t-0.13. /Strontium-90/[Hopkins BJ; Hlth Phys 13 (9): 973-6 (1967)] **PEER REVIEWED**

The results of the study of strontium-85 metabolism in 44 healthy young men aged 23+/-2 yr are presented. During the 3-6 months after intravenous injection (eight human subjects) or oral administration (36 human subjects) of the label retention of strontium-85 in the organisms was measured. During the 5-8 days following the administration the values of the complete strontium-85 excretion were studied. The coefficient of absorption of strontium-85 from the GI tract into the blood stream was estimated to be 28+/-2.5. It was demonstrated that the data on strontium-85 retention in the organism of normal young men for the time period of 3-6 months following the injection may be approximated by the following equation: R(t) = (0.79+/-0.05)t-(0.18+/-0.04).[Likhtarev IA et al; Hlth Phys 28 (1): 49-60 (1975)] **PEER REVIEWED**

The absorption of strontium-85 was investigated in an experiment on 12 volunteers, with undamaged and traumatized human skin (scratches). The skin scratches were applied with a metal grater in the region of the forearm. The absorption of strontium-85 through skin was measured on the basis of external gamma-radiation measurements from the whole body, bone tissue (patella), and from data on the daily excretion of strontium-85, which were compared with data obtained after intravenous injection of the radionuclide. Six hours after contact, 0.26% of strontium-85 applied is absorbed through undamaged skin. Over the same period 57.4% of strontium-85 applied is absorbed through damaged skin or more than 200 times as much as undamaged skin. Most of strontium-85 is absorbed during the first 30 min after application, amounting to 38.0% of the total quantity applied. /Strontium-85/[Ilyin LA et al; Hlth Phys 29 (1): 75-80 (1975)] **PEER REVIEWED**

Assessments of potential internal exposures of the child following radionuclide intakes by the mother require consideration of transfers during lactation as well as during pregnancy. Current ICRP work on internal dosimetry includes the estimation of radiation doses to newborn infants from radionuclides ingested in mothers' milk. Infant doses will be calculated for maternal intakes by ingestion or inhalation of the radionuclides, radioisotopes of 31 elements, for which fetal dose coefficients have been published. In this paper, modeling approaches are examined, concentrating on models developed for iodine, cesium, polonium, alkaline earth elements and the actinides. Comparisons of model predictions show maximum overall transfer to milk following maternal ingestion during lactation of about 30% of ingested activity for iodine-131, 20% for calcium-45 and cesium-137, 10% for strontium-90, 1% for polonium-210 and low values of less than 0.01% for plutonium-239 and americium-241. The corresponding infant doses from milk consumption are estimated in preliminary calculations to be about two to three times the adult dose for calcium-45 and iodine-131, 70-80% of the adult dose for strontium-90, about 40% for cesium-137, 20% for polonium-210, and < 0.1% for plutonium-239 and americium-241. Infant doses from radionuclides in breast milk are compared with doses to the offspring resulting from in utero exposures during pregnancy.[Harrison JD et al; Radiat Prot Dosimetry 105 (1-4): 251-6 (2003)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=14526966" target=new>PubMed Abstract

Strontium-90 is now present in the skeletons of all living persons throughout the world as a result of nuclear detonations. Since this isotope is nonuniformly distributed within the adult skeleton, it is necessary to define this distribution in order to more adequately estimate the resultant radiation hazard as well as to evaluate and compare data from a variety of bones of different individuals. The principal bones from many cadavers were analyzed. While some skeletons were assayed very extensively, the bulk of the investigation centered on rib, vertebrae and long bone shaft. In the case of adults, an aliquot of the total body skeleton was also analyzed in each case. In adults the strontium-90 concentration per gram calcium in vertebrae, rib and long bone shaft is 1.8, 1.1 and 0.5 times skeletal average respectively. In newborns and young children, the distribution is much more uniform although these data are more limited. These findings together with the fact that stable strontium is uniformly distributed throughout the adult skeleton show that the nonuniformity of strontium-90 is a temporal function of changing diet. If radiation damage from strontium-90 is a threshold phenomena, the distribution is of particular importance since the highest local concentration areas will first exceed the threshold. If the damage is nonthreshold in character, the distribution is still of some significance since some areas (e.g. bone marrow) are presumably more susceptible to radiation damage than other areas. /Strontium-90/[Schulert AR et al; Hlth Phys 2 (1): 62-8 (1959)] **PEER REVIEWED**

The comparative secretion of calcium-45 and strontium-89 into the milk of goats and dairy cows under typical farm management was studied. The effects of calcium and stable strontium levels were investigated by using four diets containing 0.25 per cent Ca, 0.50 per cent Ca, 1.6-1.7 per cent Ca, and 0.25 per cent Ca plus 2.8-2.9 per cent stable strontium. The comparative behavior of calcium and strontium was the same on all diets except for a possible renal effect with the goats. The Sr89/Ca45 of the milk was consistently about 0.12 that of the dietary intake (ORmilk-diet = 0.12). The relative contributions to the discrimination against strontium have been estimated for the important physiological processes, i.e. absorption from the digestive tract, passage from blood to milk and renal excretion. On the medium-calcium diet at steady state the dairy cows secreted into milk about 0.08 per cent of the ingested Sr89 per liter; the goats, primarily because of body size, secreted much more, about 1.4 per cent of ingested Sr89 per liter of milk. Since the ORmilk-diet value did not vary with changes in dietary calcium levels it would be expected that long-term feeding of increased dietary levels of non-contaminated calcium would produce proportional decreases in the amounts of ingested radiostrontium appearing in milk; there would seem to be no advantage in the use of stable strontium for this purpose. /Calcium-45 and strontium-89/[Comar CL et al; Hlth Phys 7 (1): 69-80 (1961)] **PEER REVIEWED**

Data on the short-term retention of strontium-85 in twenty-three human subjects are presented. Following a single intravenous injection, body burdens were measured in a total body counter facility at frequent intervals over periods ranging up to several months. Eleven subjects were on metabolic balance regimens in the hospital so that urines and stools were collected and assayed for strontium-85 and Ca. This group includes examples of the extremes of skeletal calcium metabolism including those with avid retention of Ca, normal or balanced cases, and those with large daily loss of endogenous Ca. The amounts of strontium-85 excreted soon after administration varied widely among individuals and reflected the state of Ca metabolism for each person. Retention could be expressed as a power function of time R = atb, with values of the slope b ranging from -0.83 in cases of negative Ca balance to -0.12 in a case with large positive balance. Normals ranged -0.27 to -0.29. Repetitive monitoring of knee and tibia areas divulged no reliable correlation with total body retention. ... /Strontium-85/[MacDonald NS et al; Hlth Phys 11 (11):

1187-94 (1965)] **PEER REVIEWED**

The uptake, distribution, and retention of strontium-90 was determined in rats and dogs during and after a period of prolonged administration. Groups of rats either 1, 4, or 7 months old initially were fed either 5x10-4 or 1x10-2 uCi strontium-90 per day for periods ranging from about 200-600 days. Dogs, 1 and 2 yr old, were fed 0.01 uCi strontium-90 for over 1000 days. After the cessation of strontium-90 feeding, body burdens were determined in both species for an additional 100-500 days. Skeletal strontium-90 concentrations were 10-1000 times greater than concentrations found in soft tissues. In rats, body burdens reached a dynamic balance between accumulation and elimination after about 4 months of strontium-90 administration in rats started at 1 to 1.5 months of age, and in about 1 yr in rats which were 4 months old at the start of the experiment. In dogs, a constant body burden was achieved after about 17 months of strontium-90 feeding. The strontium accumulation multiple (body burden/daily intake) ranged between 7 and 10 in adult rats and was 17 in the 1.5-month-old rats. The accumulation multiple for dogs did not exceed 44. After 2.8 yr on the strontium-containing diet, the dog skeletons were reasonably uniformly labeled and minimal and maximal strontium concentration in individual bones did not differ by more than a factor of 1.8. Elimination of strontium-90 was described by exponential models whose maximum effective half life in rats ranged between 533 and 593 days; in dogs, it was calculated to be 530 days. /Strontium-90/[Moskalev Y I, Buldakov L A; Hlth Phys 15 (3): 229-35 (1968)] **PEER REVIEWED**

Results obtained in metabolic studies of stable strontium and of strontium-90 which were naturally contained in the diet and the excretions and retention of strontium-85 following oral or intravenous administration of tracer doses of strontium-85 were compared in groups of adult males who were studied under strictly controlled dietary conditions. This comparison has shown good agreement between the results obtained with stable strontium, strontium-90 and strontium-85. The net absorption of stable strontium, of strontium-90 and of strontium-85 averaged 12%, 16% and 20%, respectively. The urinary excretions expressed as percent of the intake averaged 17% and 13% for stable strontium and for strontium-90 respectively, and was lower following the acute administration of strontium-85. There was a good correlation between the urinary excretion of calcium and of each of the three strontium isotopes. In general, very low levels of the urinary calcium were associated with very low levels of urinary ... strontium and vice versa; high excretions of calcium were associated with relatively high excretions of these isotopes. The fecal excretions of the three isotopes were rather high and were similar for stable strontium, strontium-90 and strontium-85, the average values ranging from 81 to 88% in the three studies. /Stable strontium, strontium-90 and strontium-85/[Warren JM, Spencer H; Hlth Phys 34 (1): 67-70 (1978)] **PEER REVIEWED**

BIOLOGICAL HALF-LIFE:

Biodistribution of elements in human adults: Strontium, Principal deposition sites, skeleton (25 % entering blood); Retention half-time > or = 20 years /from table/[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 65 (2001)] **PEER REVIEWED**

For radionuclides such as strontium-90 ... with a long physical half-life and a long biological half-time in the body, radiation exposure after an intake will generally be for the remaining lifespan of the animal ... /Strontium-90/[United Nations Scientific Committee on the Effects of Atomic Radiation. UNCSCEAR 2000 Report to the General Assembly, with Scientific Annexes: Sources and Effects of Ionizing Radiation V 2 p.98 (2000)] **PEER REVIEWED**

INTERACTIONS:

Studies of the effects of the chelating agent, calcium acetylamino propylidene diphosphonic acid (Ca-APDA), on the removal of radioactive strontium with two administration modalities were carried out in rats. The parenteral (intraperitoneal) administration of 150, 300, or 600 mg kg-1 Ca-APDA was carried out for 3 d, 10 min after exposure of the animals to the strontium injection. On the first day post-treatment, the retention of strontium in the whole body decreased to 90.1%, 83.9%, and 35.1% that of the control level, respectively. The strontium deposited in femur of 600 mg kg-1 Ca-APDA group was lowered to 28.4% of the control value. A single oral dose of 600 mg kg-1 Ca-APDA administered simultaneously with, or 10 min after, oral administration of strontium, radionuclide retention in the whole body was reduced after 1 d to 42.9% and 31.9% of the control, respectively; meanwhile the strontium deposited in the femur was reduced to 16.9% and 29.3% of the control. In conclusion, the results indicate the efficacy of the new agent, Ca-APDA, to remove radioactive strontium from the body, or to inhibit the strontium intestinal absorption, in radio-strontium contaminated individuals. /Ca-APDA and strontium/[Fukuda S et al; Hlth Phys 76 (5): 489-494 (1999)] **PEER REVIEWED**

Rats were fed a stock diet supplemented with calcium phosphate and sodium alginate, both separately and simultaneously, over a period of 4-5 months. Observations were made at intervals on the growth rate and on visual and histological abnormalities in some body tissues. No toxic effects were observed. The absorption and skeletal retention of calcium for rats on the combined supplements remained almost unchanged but the absorption and retention of strontium was reduced 7-fold. /Sodium alginate and strontium/[Slat B et al; Hlth Phys 21 (6): 811-4 (1971)] **PEER REVIEWED**

In tracer kinetic investigations, the effect of sodium alginate on the gastrointestinal absorption of strontium was studied in human subjects. Sodium alginate was proven to be a potent agent for reducing strontium absorption with high efficiency and virtually no toxicity. The data obtained show that the uptake of ingested strontium from milk was reduced by a factor of nine when alginate was added to milk. It is concluded that alginate preparations are a suitable antidote against radiostrontium. /Radiostrontium and sodium alginate/[Hollreigl V et al; Hlth Phys 86(2):193-6. (2004)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=14744054" target=new>PubMed Abstract

Many trials based on the basic phenomena of isotopic dilution, adsorption, ion exchange, chelation, etc., have been attempted for the decorporation of radiostrontium, particularly strontium-90, after its entry in the in vivo system. /The authors/ have recently demonstrated a non-isotopic carrier effect of some common calcium salts (calcium = 9 mg/mL) to reduce the whole body retention of radiostrontium, if administered within 2 h after radiostrontium exposure and furthermore once daily, in rats, supplemented with calcium fortified diet. However, 25-30% of radiostrontium (compared to 50-60% in untreated animals) was still found to be retained in the animal even after 2 wk of treatment. Trial of some simple interventional measures, which would not adversely affect the animal metabolism, like pyrophosphate and magnesium sulfate, sodium citrate, chitin (a bio-absorbent), crown ether (a metal-chelator), and ammonium chloride, was therefore attempted to dislodge this remaining radiostrontium by switching over these animals to normal diet and subjecting them to different lines of treatment with these simple interventions through diet and drinking water separately for a further 4 wk. However, this remaining portion of radiostrontium is fixed in the bone and is difficult to dislodge. /Radiostrontium and calcium salts/[Sonawane VR et al; Hlth Phys 87 (1): 46-50 (2004)] **PEER REVIEWED**

Ingestion: A number of factors have been found to increase the absorption of strontium, including fasting and low dietary levels of calcium, magnesium and phosphorus; milk diets and vitamin D may also increase absorption. ... The results of animal studies are generally similar to those for volunteers.[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 338 (2001)] **PEER REVIEWED**

PHARMACOLOGY:

THERAPEUTIC USES:

The radioactive isotope strontium-89 (also known by the pharmaceutical brand name Metastro) is used as a cancer therapeutic to alleviate bone pain. Strontium-85 has been used in medical applications, such as radiologic imagining of bones.[ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

The aim of this article was to review the available literature regarding to the use of strontium-89 in the palliation of osteoblastic bone pain. The data of many researchers showed that approximately 80% of patients with pain from osteoblastic lesions resulting from prostate or breast cancer experience significant pain relief by administration of strontium-89, with only mild levels of hematotoxicity. The duration of pain relief in some cases exceeded 3-6 months. Indications for administration of strontium-89, effectiveness and duration of the treatment, side effects are reviewed in this article. /Strontium-89/[Baranauskas Z et al; Medicina (Kaunas) 42 (1): 11-4 (2006)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=16467608" target=new>PubMed Abstract

Implants of strontium-90 provide radiation therapy for the treatment of the pituitary gland and breast and nerve tissue.[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-155 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf] **PEER REVIEWED**

BACKGROUND: Postcoronary angioplasty vascular brachytherapy (VBT) has emerged as a successful intervention for restenosis prevention in some clinical scenarios. /Strontium-90/[Meerkin D et al; Circulation 30; 106 (5): 539-43 (2002)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12147533" target=new>PubMed Abstract

/VET/ ... Medical records of cats with cutaneous mast cell tumors (CMCTs) in which tumors were radiated by use of a strontium-90 ophthalmic applicator from 1992 to 2002 were reviewed. Cats were included if CMCT was diagnosed, there were no other sites of MCT involvement at the time of treatment, and records contained adequate follow-up information to permit retrospective assessment of local tumor control. ... 54 tumors in 35 cats were treated with a median dose of 135 Gy of strontium-90 beta irradiation, resulting in local tumor control in 53 of 54 (98%) tumors with a median follow-up time of 783 days after treatment. Median survival time was 1,075 days. Adverse effects of treatment appeared to be infrequent and of mild severity. ... /Strontium-90/[Turrel JM et al; J Am Vet Med Assoc 228 (6): 898-901 (2006)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=16536702" target=new>PubMed Abstract

In contrast to the smaller amount of radioactivity utilized in diagnostic nuclear medicine, larger amounts of radioactivity are intentionally chosen for use in therapeutic nuclear medicine. Therapy in nuclear medicine involves oral, intravenous, or intracavitary delivery of radionuclides in liquid form (sometimes called "unsealed" radionuclides). The radionuclide is chosen with the aim of ensuring that subsequent physiological redistribution will concentrate the radioactivity in the target tissue and, at the same time, reduce the radioactivity in surrounding normal tissues. Radionuclides suitable for use in therapeutic nuclear medicine must either localize in their elemental form (such as iodine uptake in the thyroid gland) or be bound to an appropriate pharmaceutical or antibody. Radionuclides commonly used for therapeutic nuclear medicine include: colloidal gold-198; iodine-131 as sodium iodine, meta-iodobenzylguanidine, monoclonal antibodies; colloidal phosphorous-32; and Sr-89 chloride /from table/. /Iodine-131, colloidal 32-P, strontium-89/[NAS/Institute of Medicine; Radiation in Medicine: A Need for Regulatory Reform (1996)] **PEER REVIEWED**

As an adjunct to surgical removal of the pterygium /a raised, wedge-shaped growth of the conjunctiva/, a solid strontium-90 source is apposed to the site in order to reduce neovascularization.[DHHS/ATSDR Toxicological Profile for Strontium p 107-8 (2004)] **PEER REVIEWED**

DRUG WARNINGS:

As an adjunct to surgical removal of the pterygium, a solid strintium-90 source is apposed to the site in order to reduce neovascularization. Several clinical studies reported complications resulting from this procedure. ... Atrophy of the sclera occurred after a dose of 1,600 rad from 90-Sr. In a later study, 78 eyes in 62 patients were treated with 1,080 rad (10.8 Gy) of beta radiation from a 90-Sr source repeated at weekly intervals (total dose 3,200 rad; 32 Gy). Six patients were retreated ... One eye, which had received treatments of 5,380 rad (53.8 Gy) each to two adjacent fields, developed keratitis of the cornea. Other complications noted were telangiectasis of the conjunctiva (27%), scarring of the conjunctiva (14%), and scarring of the cornea (3%). ... A complication rate of 1.8% was reported for a study of 490 eyes (399 patients) that received doses between 31 and 42 Gy (3,100 - 4,200 rad) in four or five fractions over 29 days. Scleral thinning, not severe enough to require treatment, was reported for four eyes in three patients.[DHHS/ATSDR Toxicological Profile for Strontium p 107-8 (2004)] **PEER REVIEWED**

INTERACTIONS:

Studies of the effects of the chelating agent, calcium acetylamino propylidene diphosphonic acid (Ca-APDA), on the removal of radioactive strontium with two administration modalities were carried out in rats. The parenteral (intraperitoneal) administration of 150, 300, or 600 mg kg-1 Ca-APDA was carried out for 3 d, 10 min after exposure of the animals to the strontium injection. On the first day post-treatment, the retention of strontium in the whole body decreased to 90.1%, 83.9%, and 35.1% that of the control level, respectively. The strontium deposited in femur of 600 mg kg-1 Ca-APDA group was lowered to 28.4% of the control value. A single oral dose of 600 mg kg-1 Ca-APDA administered simultaneously with, or 10 min after, oral administration of strontium, radionuclide retention in the whole body was reduced after 1 d to 42.9% and 31.9% of the control, respectively; meanwhile the strontium deposited in the femur was reduced to 16.9% and 29.3% of the control. In conclusion, the results indicate the efficacy of the new agent, Ca-APDA, to remove radioactive strontium from the body, or to inhibit the strontium intestinal absorption, in radio-strontium contaminated individuals. /Ca-APDA and strontium/[Fukuda S et al; Hlth Phys 76 (5): 489-494 (1999)] **PEER REVIEWED**

Rats were fed a stock diet supplemented with calcium phosphate and sodium alginate, both separately and simultaneously, over a period of 4-5 months. Observations were made at intervals on the growth rate and on visual and histological abnormalities in some body tissues. No toxic effects were observed. The absorption and skeletal retention of calcium for rats on the combined supplements remained almost unchanged but the absorption and retention of strontium was reduced 7-fold. /Sodium alginate and strontium/[Slat B et al; Hlth Phys 21 (6): 811-4 (1971)] **PEER REVIEWED**

In tracer kinetic investigations, the effect of sodium alginate on the gastrointestinal absorption of strontium was studied in human subjects. Sodium alginate was proven to be a potent agent for reducing strontium absorption with high efficiency and virtually no toxicity. The data obtained show that the uptake of ingested strontium from milk was reduced by a factor of nine when alginate was added to milk. It is concluded that alginate preparations are a suitable antidote against radiostrontium. /Radiostrontium and sodium alginate/[Hollreigl V et al; Hlth Phys 86(2):193-6. (2004)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=14744054" target=new>PubMed Abstract

Many trials based on the basic phenomena of isotopic dilution, adsorption, ion exchange, chelation, etc., have been attempted for the decorporation of radiostrontium, particularly strontium-90, after its entry in the in vivo system. /The authors/ have recently demonstrated a non-isotopic carrier effect of some common calcium salts (calcium = 9 mg/mL) to reduce the whole body retention of radiostrontium, if administered within 2 h after radiostrontium exposure and furthermore once daily, in rats, supplemented with calcium fortified diet. However, 25-30% of radiostrontium (compared to 50-60% in untreated animals) was still found to be retained in the animal even after 2 wk of treatment. Trial of some simple interventional measures, which would not adversely affect the animal metabolism, like pyrophosphate and magnesium sulfate, sodium citrate, chitin (a bio-absorbent), crown ether (a metal-chelator), and ammonium chloride, was therefore attempted to dislodge this remaining radiostrontium by switching over these animals to normal diet and subjecting them to different lines of treatment with these simple interventions through diet and drinking water separately for a further 4 wk. However, this remaining portion of radiostrontium is fixed in the bone and is difficult to dislodge. /Radiostrontium and calcium salts/[Sonawane VR et al; Hlth Phys 87 (1): 46-50 (2004)] **PEER REVIEWED**

Ingestion: A number of factors have been found to increase the absorption of strontium, including fasting and low dietary levels of calcium, magnesium and phosphorus; milk diets and vitamin D may also increase absorption. ... The results of animal studies are generally similar to those for volunteers.[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 338 (2001)] **PEER REVIEWED**

ENVIRONMENTAL FATE & EXPOSURE:

ENVIRONMENTAL FATE/EXPOSURE SUMMARY:

Most of the radioactive strontium released to the environment occurred as a result of atmospheric testing of nuclear weapons from 1945-1980. Nuclear weapon testing injects radioactive material into the stratosphere, which results in wide dispersal of radioactive strontium and other radionuclides. The World Health Organization estimated the total amount of strontium-90 released to the atmosphere from weapons testing was 1.6X10+7 Ci (6X10+17 Bq) during the period of 1945-1980. The accident at the Chernobyl nuclear power plant in the Ukraine (April 1986) also resulted in the release of about 2.2X10+6 Ci (8.1X10+16 Bq) of strontium-89 and 2.2X10+5 Ci (8.1X10+15 Bq) of strontium-90 into the atmosphere. Since the radioactive decay half-life of strontium-89 is relatively short (51 days), its global transport and the extent of human exposure is limited. The half-life of strontium-90 is much longer (29 years) and some strontium-90 reached the upper atmosphere and was subsequently transported around the world. Routine releases of radioactive strontium also occur from the operation and maintenance of nuclear power plants, but these levels are insignificant when compared to the levels released from the atmospheric testing of nuclear weapons and the accident at the Chernobyl nuclear power plant. The environmental fate of the radioactive forms of strontium is expected to be similar to those of the stable (non-radioactive) form. When released to the atmosphere, radioactive strontium exists in the particulate-phase and is removed by wet and dry deposition. Strontium has moderate mobility in soils and sediments, and adsorbs moderately to metal oxides and clays. Strontium bioconcentrates in aquatic organisms and accumulates in bones of both aquatic and terrestrial animals. BCF values for strontium-90 ranged from 48 to 3,400 in fish muscle, but were 2,400 to 63,000 in bones. Workers employed in the nuclear industry may be accidentally exposed to strontium-89 and strontium-90 through oral, dermal, and inhalation routes. Since atmospheric testing of nuclear weapons has been discontinued for many years and Chernobyl-related fallout was low in the US, current exposure of the general population of the US to radioactive strontium is expected to be low. The primary route of exposure to radioactive strontium for the general population is through ingestion of food, dairy products, and drinking water. Strontium-90 is deposited directly onto plant and soil surfaces and may be translocated to plants through foliar absorption and root uptake. Vegetation consumed by animals such as cows, goats, reindeer, etc, may eventually transfer strontium-90 to the human food chain through the ingestion of beef, milk, or other dairy products. The average daily intake for strontium-90 in the US peaked in 1968 at about 1.1 Bq/day and has slowly declined over the past 40 years to less than 0.05 Bq/day. (SRC) **PEER REVIEWED**

PROBABLE ROUTES OF HUMAN EXPOSURE:

NIOSH (NOES Survey 1981-1983) has statistically estimated that 4,656 workers (533 of these are female) are potentially exposed to strontium-90 in the US(1). Workers employed in the nuclear industry may be exposed to strontium-89 and strontium-90 through oral, dermal, and inhalation routes(2). The radioactive half-life of strontium-89 is short in comparison to strontium-90; therefore, the potential exposure to workers and the general population is considerably lower for strontium-89 as compared to strontium-90. A case of accidental inhalation and dermal exposure to strontium-90 was reported for two workers handling waste containers holding strontium-90 waste(3). The strontium-90 intake for one of the workers was estimated as 2.6X10+5 Bq and was 6.6X10+4 Bq for the second employee(3).[(1) NIOSH; National Occupational Exposure Survey. Sr-90. 10098-97-2. Available http://www.cdc.gov/noes/noes1/x3148sic.html as of Sept 30, 2005. (2) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004) (3) Navarro T, Lopez MA; Radiat Prot Dosim 79: 67-70 (1998)] **PEER REVIEWED**

Current exposure of the general US population to strontium-89 and strontium-90 is expected to be low since atmospheric testing of nuclear weapons has been discontinued for several years and Chernobyl-related fallout was low in the United States(1). The primary route of exposure is through oral ingestion of foods and water containing radioactive strontium and possibly inhalation of aerosols(1).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

Plants acquire strontium-90 through atmospheric deposition and uptake through the roots. Root uptake from soil is the primary pathway. Cows, reindeer and other animals consume vegetation containing strontium-90 and ultimately it may be transferred to the human food chain via milk, beef, etc(1).[(1) WHO; Selected radionuclides: Tritium, carbon-14, krypton-85, strontium-90, iodine, caesium-137, radon, plutonium. Environmental Health Criteria 25. Geneva: World Health Organization. (1983)] **PEER REVIEWED**

BODY BURDEN:

The distributions of strontium-90 in the body are significantly different for males and females(1). As expected, the highest concentrations of strontium-90 are measured in the boney tissue. Males averaged and females averaged 10.4 and 65 pCi/kg (0.38 and 2.4 Bq/kg) wet weight, respectively(1). Males had a much higher concentration of strontium-90 in muscle tissue compared to females. The heart and psoas muscles had respective concentrations of strontium-90 for men averaging 13.9 and 18.7 pCi/kg (0.51 and 0.69 Bq) wet weight versus respective concentrations of 7.4 and 1.9 pCi/kg (0.27 Bq/kg and 70 mBq/kg) wet weight for females (1). The strontium-90 activities in teeth collected from the Ukraine ranged from 0.027 to 0.44 pCi/g(1). A worker that was accidently exposed to strontium-90 while handling waste containers had a strontium-90 urinary excretion rate of approximately 544 Bq/day, one day post exposure(2). The urinary excretion rate decreased exponentially and was < 1 Bq/day 212 days later(2).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004) (2) Navarro T, Lopez MA; Radiat Prot Dosim 79: 67-70 (1998)] **PEER REVIEWED**

AVERAGE DAILY INTAKE:

The AVDI of strontium-90 in the US peaked in 1963 at approximately 1.1 Bq/day and has steadily decreased(1). The current AVDI of strontium-90 in the US is less than 0.05 Bq/day(1).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

ARTIFICIAL POLLUTION SOURCES:

Reactor releases of strontium-90 or from bomb tests.[Koss V, Kim JI; J Contaminant Hydrology 6: 267-80 (1990)] **PEER REVIEWED**

The radioactive isotopes of strontium are formed during nuclear fission, in commercial applications such as the generation of electricity at nuclear power plants. The most abundant radioisotopes that are formed in this manner are strontium-89 and strontium-90(1). The largest releases of strontium-89 and strontium-90 have occurred as a result of atmospheric testing of nuclear weapons, and the accident at the Chernobyl nuclear power plant(1).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

ENVIRONMENTAL FATE:

TERRESTRIAL FATE: Strontium has moderate to low mobility in soil, depending upon the environmental conditions, particularly the level of salinity in the soil water. Soil adsorption coefficients (Kd) in the range of 56 to 62 L/kg were measured using aquifer sediments beneath waste water ponds at the Idaho National Environmental and Engineering Laboratory (INEEL) for initial aqueous sodium and potassium levels equal to or less than 300 mg/L and 150 mg/L, respectively(1). A significant decrease in strontium-90 adsorption was observed when dissolved levels of sodium and potassium increased. Kd values ranged from 4.7 to 19 for sodium levels of 1,000 to 5,000 mg/L(1).[(1) Bunde RL et al; Environ Geol 34: 135-142

(1998)] **PEER REVIEWED**

AQUATIC FATE: High salt concentrations (marine, brines, or high salinity water) can increase the mobility of strontium-90 by decreasing strontium sorption to sediments and increase the transport of strontium with the environmental cycling of water(1). Strontium bioconcentrates in aquatic organisms, but due to its similarities with calcium, tends to accumulate in bones(2). Fish BCF values of strontium-90 ranged from 48 to 3,400 in muscle and edible portions, but were 2,400 to 63,000 in bones(2).[(1) Bunde RL et al; Environ Geol 34: 135-142 (1998) (2) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

ATMOSPHERIC FATE: Strontium exists in the particulate phase in the atmosphere and is removed from air by wet and dry deposition. The transport and partitioning of particulate matter in the atmosphere is largely dependent upon the physical properties of the matter such as size and density as well as the meteorological conditions such as temperature, the microphysical structure of the clouds, and rainfall rate. The particle size of most radionuclides released to the atmosphere following the Chernobyl nuclear accident was in the range of 0.1-10 um(1). Particles < 5 um in diameter usually have low deposition velocities and are transported long distances before being removed from the atmosphere. Strontium-90 had a larger particle size distribution than other radionuclides such as cesium-137, and subsequently had greater deposition near the source of the accident(1). Following the accident at the Chernobyl nuclear power plant, the wet deposition velocity of strontium-90 measured at Tsukauba, Japan from May 5 to May 30, 1986 ranged from 0.016 to 0.230 m/second, with the largest values recorded during a period of heavy rainfall(1). The flux rate of strontium-90 ranged from 0.038-0.62 Bq/sq m-day(1). The average total annual wet deposition flux of strontium-90 in the United States was 0.2 Bq/sq m-year in 1990(2).[(1) Hirose K et al; J Atmos Chem 17: 61-71 (1993) (2) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

ENVIRONMENTAL ABIOTIC DEGRADATION:

Radioactive forms of strontium are continuously transformed to stable isotopes by the natural process of radioactive decay(1). Strontium-90 has a radioactive decay half-life of 29 years, while strontium-89 has a much shorter half-life (51 days)(1). Strontium-90 decays by emission of a beta-particle with a maximum energy of 0.546 MeV and the creation of a yttrium-90 isotope, which is also unstable. Yttrium-90 decays by beta-particle and gamma ray emission to the stable zirconium-90 isotope(1). Strontium-89 decays to yttrium-89 by emission of a negative beta-particle with a maximum energy of 1.495 MeV(1).[(1) ATSDR; Toxicological Profile for Strontium (Draft for Public Comment). Atlanta, GA: Agency for Toxic Substances and Disease Registry (2004)] **PEER REVIEWED**

ENVIRONMENTAL BIOCONCENTRATION:

Strontium has been shown to bioconcentrate and bioaccumulate in both terrestrial and aquatic food chains(1). Maximum BCF values of 48 to 3,400 were reported for fish muscle, while values in the range of 2,400 to 63,000 were reported for bone in fish obtained from the Department of Energy Savannah River Site(1). Because strontium and calcium are chemically similar, the concentration of calcium in water can influence the bioaccumulation of strontium in biota. Organisms such as fish bioaccumulate strontium with an inverse correlation to levels of calcium in water. However, this correlation is not universal and does not apply to other organisms such as algae and plants(1).[(1) ATSDR; Toxicological Profile for Strontium (Draft for Public Comment). Atlanta, GA: Agency for Toxic Substances and Disease Registry (2004)] **PEER REVIEWED**

SOIL ADSORPTION/MOBILITY:

The rate of strontium-90 adsorption as a function of aqueous sodium and potassium ion concentrations was studied using aquifer sediments beneath waste water ponds at the Idaho National Environmental and Engineering Laboratory (INEEL)(1). Soil adsorption coefficients (Kd) in the range of 56 to 62 L/kg were measured for initial aqueous sodium and potassium levels equal to or less than 300 mg/L and 150 mg/L, respectively(1). A significant decrease in strontium-90 adsorption was observed when dissolved levels of sodium and potassium increased. Kd values decreased to 4.7 to 19 for sodium levels of 1,000 to 5,000 mg/L(1). These data indicate that sodium and potassium compete with strontium for cation exchange sites in the soil, and in areas with high salinity, the mobility of strontium will be greater than in areas with low dissolved sodium and potassium levels. Similar results have been observed for soils containing high levels of Mg+2 and Ca+2 ions(2). A strontium-90 plume in glacial sediments was studied at the Chalk River Nuclear Laboratory in Ottawa Canada(2). The plume migrated about 300 meters over the course of 30 years. The mobility of strontium-90 was greatest following an accidental spill from a nearby nitrate processing plant that accidentally released high levels of calcium and magnesium. The plume advanced rapidly as the strontium-90 was outcompeted for cation adsorption sites by Mg+2 and Ca+2 ions, but slowed significantly as the levels of calcium and magnesium declined(2).[(1) Bunde RL et al; Environ Geol 34: 135-142 (1998) (2) Toran L; in Environ Sci Pollut Control Ser. NY, NY: M Dekker, 11(Groundwater Contam. And Control): 437-55 (1994)] **PEER REVIEWED**

The downward movement of strontium in soil is slow, although it is more rapid than for cesium-137 or plutonium-249(1). Even after several years, strontium-90 remains in the upper few centimeters in undisturbed soil. The rate of movement varies with soil type; a low content of clay and humus, a high content of electrolytes, and a rapid movement of water increases mobility(1).[(1) WHO; Selected radionuclides: Tritium, carbon-14, krypton-85, strontium-90, iodine, caesium-137, radon, plutonium. Environmental Health Criteria 25. Geneva: World Health Organization. (1983)] **PEER REVIEWED**

ENVIRONMENTAL WATER CONCENTRATIONS:

DRINKING WATER: The EPA ERAMS program monitors ambient concentrations of strontium-90 in drinking water at 78 sites in major population centers or near selected nuclear facilities. The median activity of strontium-90 in drinking water for 1995 was 0.1 picoCuries per liter (pCi/L)(1). Sites with the highest levels of strontium-90, Detroit and Niagara Falls, recorded activities of 0.4 and 0.5 pCi/L, respectively(1). In a 1974 study, 0.09 pCi/L of strontium-90 was measured in Los Angeles, California drinking water(1). In a survey that examined 169 wells used for public drinking water in California, 16 wells measured recordable concentrations of strontium-90, with a range of 8 to 330 pCi/L(2).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004) (2) Storm DL;in Water contamination and health: Integration of exposure assessment, toxicology, and risk assessment. Wang RGM, ed. Marcel Dekker, Inc: New York, NY (1994)] **PEER REVIEWED**

GROUNDWATER: The concentrations of strontium-90 in groundwater at the 91 waste sites located at 18 DOE facilities were between 0.05 and 231,000 pCi/L(1). Dissolved strontium-90 was detected in groundwater at 19 out of 101 sites in the US, with median and average activities of 1,900 and 1,380 pCi/L (70 and 51 Bq), respectively(2). The level of strontium-90 in groundwater samples obtained from the 30 km exclusion zone surrounding the Chernobyl reactor were 576 pCi/L (April 16, 1987); 7.6 pCi/L (May 4, 1988); 11.6 pCi/L (July 7, 1988); 3.9 pCi/L (August 24, 1989); 7.9 pCi/L (April 11, 1990); 46.8 pCi/L (January 10, 1991)(2).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004) (2)

Dzhepo S et al; pp 72-74 in Groundwater Quality: Remediation and Protection. IAHS Publ. No. 250, Herbert M, Kovar K, eds., IAHS Press: Wallingford, UK (1998)] **PEER REVIEWED**

SURFACE WATER: According to the National Drinking Water Contaminant Occurrence Database (NDOD), strontium-90 was detected in surface waters at one out of nine US sites (11.1% of sites), with an average activity of 0.5 pCi/L(1). Strontium-90 in surface waters of the north Pacific Ocean has decreased steadily since the early 1960s to present day levels of approximately 0.923 to 0.081 pCi/L sea water(1). Strontium-90 levels measured in the Catalan Sea (Northwestern Mediterranean) ranged from 0.015 to 0.05 pCi/L in August of 1993(2). The mean activity of strontium-90 measured in the Ebro River, Spain in 1994 was 0.17 pCi/L(3).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004) (2) Merino J et al; Radioprot Colloques 32: C285-C290 (1997) (3) Pujol L, Sanchez-Cabeza JA; J Environ Radioact 51: 181-210 (2000)] **PEER REVIEWED**

EFFLUENT CONCENTRATIONS:

Most of the radioactive strontium released to the environment occurred as a result of atmospheric testing of nuclear weapons from 1945 to 1980. According to the World Health Organization, the total amount of strontium-90 released to the atmosphere from weapons testing was 1.6X10+7 Ci (6X10+17 Bq) from 1945-1980(1). The accident at the Chernobyl nuclear power plant in April, 1986 also released about 2.2X10+6 Ci (8.1X10+16 Bq) of strontium-89 and 2.2X10+5 Ci (8.1X10+15 Bq) of strontium-90 into the atmosphere(2). On January 24, 1978, the Soviet nuclear-powered satellite Cosmos 954 re-entered earth's atmosphere over the Canadian Arctic, releasing an estimated 83 Ci of strontium-90(2). Between 1944 and 1972, about 64 Ci of strontium-90 and 700 Ci of strontium-89 was released into the atmosphere at the DOE Hanford site in Washington state from the routine operation of chemical plants used to separate plutonium from spent reactor fuel(2). Radioactive strontium released in airborne and water effluents from the normal operation of nuclear power plants is considered low in comparison to releases from atmospheric weapons testing and the major releases following accidents at nuclear power plants. Water effluents from 29 boiling water reactor (BWR) and 45 pressurized water reactor (PWR) nuclear power plants in the United States released a total of 0.2071 Ci, 0.1828 Ci, 4X10-5 Ci, and 0.0115 Ci of strontium-89, strontium-90, strontium-91, and strontium-92, respectively in 1993(2). Airborne effluents were 5X10-4 Ci, 2X10-5 Ci, and 0.0027 Ci for strontium-89, strontium-90, and strontium-91, respectively(2). The World Health Organization estimated that approximately 54 Ci of strontium-90 were discharged to the environment from all the nuclear power plants (241 total plants) operating globally in 1980(1).[(1) WHO; Selected radionuclides: Tritium, carbon-14, krypton-85, strontium-90, iodine, caesium-137, radon, plutonium. Environmental Health Criteria 25. Geneva: World Health Organization. (1983) (2) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

SEDIMENT/SOIL CONCENTRATIONS:

SEDIMENT: The annual mean level of strontium-90 in sediment from a segment of the Danube River, Hungary ranged from 47.3 to 192.9 pCi/kg for samples collected from 1983 to 1988(1). The mean activity of strontium-90 in lucustrine and marine sediments from Antarctica in 1989-1996 ranged from 4.59 to 20.5 pCi/kg and < 2.7 to 5.78 pCi/kg, respectively(2). Marine sediments in the vicinity of two nuclear power stations in South Korea had strontium-90 activities 3.16 to 48.6 pCi/kg(2).[(1) Conkic L et al; Water Si Technol 22: 195-2002 (1990) (2) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

SOIL: The background level of strontium-90 in soils of the United States from global fallout depends upon the historical transport and deposition inventory at that particular location. The mean regional background concentration of strontium-90 in soils in proximity to the Los Alamos National Laboratory from 1974 to 1994 was 320 (+ or -) 250 pCi/kg dry weight soil(1). The range of concentrations for strontium-90 in soils and sediments at 91 wastes sites located at the 18 US Dept of Energy (DOE) facilities around the United States was 0.02 to 540,000 pCi/kg(1).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

ATMOSPHERIC CONCENTRATIONS:

Prior to the 1940's radioactive strontium was not present in the air at any significant levels(1). Concentrations of strontium-90 peaked in 1963 at approximately 1X10+7 Ci, coincident with the period of extensive nuclear weapons testing(1). Since the signing of the Nuclear Test Ban Treaty of 1963, atmospheric levels have steadily dropped. In 1975, the average concentration of strontium-90 in the air over Southwestern Poland was 1.62 pCi/cu m(2).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004) (2) Glowiak BJ et al; Environ Pollut 14: 101-111 (1977)] **PEER REVIEWED**

FOOD SURVEY VALUES:

Strontium-90 was detected at very low levels during the US Food and Drug Administration Total Diet Study from 1991 to 1996(1). The greatest strontium-90 concentration occurred in mixed nuts at 2 Bq/kg, which is 80 times lower than the regulatory level of 160 Bq/kg(1). Food items from New York City and San Francisco, CA were analyzed for strontium-90(2). The greatest levels were observed in fresh vegetables (8.8 pCi/kg dry weight) and dry beans (15.9 pCi/kg dry weight)(2).[(1) Capar SG, Cunningham WC; J AOAC Int 83: 157-77 (2000) (2) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

PLANT CONCENTRATIONS:

The average strontium-90 activity in lichens collected in the Arctic was reported as 6.46 Bq/kg(1). Six species of plants collected in Bodenmais, Bavaria in July, 1993 had strontium-90 levels as follows (leaves): Dryopteris carthusiana, 82.2; Vaccinium myrtillus, 78.8; Athyrium filix femina, 68.7; Rubus fruticosus, 43.2; Prenanthes purpurea, 29.0; Rubus idaeus, 24.9 Bq/kg dry weight(2). The uptake of strontium-90 in 10 different vegetable crops grown in contaminated soils was studied(3). The order of strontium-90 uptake in the edible portions of the plants was Radish (root) > Snapbean (fruit) > Cucumber (fruit) > Hot pepper (fruit) > Celery (stem) > Beet (root) > Celery (leaf) > Sweet pepper (fruit) > Cauliflower (fruit) > Tomato (fruit). The uptake of strontium-90 in soybeans, corn, alfalfa, and wheat was studied in various soils, and the order of strontium-90 accumulation was soybeans > corn, alfalfa > wheat(4). It was shown that the uptake and accumulation of strontium-90 in contaminated soils can be significantly reduced by liming the soil (increasing the pH), or growing crops in soils with high clay contents(4).[(1) Beresford NA et al; Radioprotection 40: 5285-9 (2005) (2) Environmental Studies; Radioecology. Sr90 in environmental samples. Environmental Studies, Duderstadt, Germany. Available at http://www.environmental-studies.de/Radioecology/Sr-90/sr-90-E.html as of Apr 27, 2006. (3) Haghari F; Ohio J Sci 64: 371-374 (1964) (4) Jones JB, Haghari F; Ohio J Sci 62: 97-100 (1962)] **PEER REVIEWED**

ANIMAL CONCENTRATIONS:

The mean concn of strontium-90 measured in deer and elk killed near low level radioactive waste disposal sites at Los Alamos National Laboratory were 12 and 7 pCi/kg, respectively, while concentrations at background locations were 3.5 and 1.7 pCi/kg, respectively(1).[(1) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

MILK CONCENTRATIONS:

Milk samples collected between 1959 and 1968 in Denmark and Faroes were found to contain strontium at concns of 8.6 to 24.7 pCi/g Ca and 0 to 154 pCi/g Ca, respectively(1).[(1) Aarkrog A; Hlth Phys 20: 297-311 (1971)] **PEER REVIEWED**

The level of strontium-90 measured in milk samples (July through September, 2003) were as follows: San Francisco, CA 0.73 pCi/L; Dover, DE 0.19 pCi/L; Atlanta, GA 0.59 pCi/L; Wichita, KS 0.42 pCi/L; Grand Rapids, MI 0.45 pCi/L; Syracuse, NY 0.53 pCi/L(1). The level of strontium-90 in pasturized milk samples from 13 US cities and San Juan, Puerto Rico ranged from 0.49 to 1.71 pCi/L(2). The average activity of strontium-90 in pasteurized milk samples collected in 42 US cities in 1997 was 0.9 pCi/L(2).[(1) USEPA; Environmental Radiation Data. Report 115. Montgomery, AL: USEPA, Off Rad and Indoor Air. Available at http://www.epa.gov/narel/ERD115.pdf as of Sept 30, (2005) (2) ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

Assessments of potential internal exposures of the child following radionuclide intakes by the mother require consideration of transfers during lactation as well as during pregnancy. Current ICRP work on internal dosimetry includes the estimation of radiation doses to newborn infants from radionuclides ingested in mothers' milk. ... Comparisons of model predictions show maximum overall transfer to milk following maternal ingestion during lactation of about 10% of ingested activity for strontium-90 ... . The corresponding infant doses from milk consumption are estimated in preliminary calculations to be about ... 70-80% of the adult dose for strontium-90 ...[Harrison JD et al; Radiat Prot Dosimetry 105 (1-4): 251-6 (2003)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=14526966" target=new>PubMed Abstract

The results of measurements of the absorption of strontium in seven-day-old infants fed cows' milk suggested values > 73%. Similar levels of absorption have been reported for 5 to 15-year-old children and adults.[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v78 338 (2001)] **PEER REVIEWED**

ENVIRONMENTAL STANDARDS & REGULATIONS:

CERCLA REPORTABLE QUANTITIES:

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 100 curies or 3.7 TBq. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b). /Strontium-80/[40 CFR 302.4: U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 21, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

Persons in charge of vessels or facilities are required to notify the

National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 1000 curies or 37 TBq. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b). /Strontium-81/[40 CFR 302.4: U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 21, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 100 curies or 3.7 TBq. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b). /Strontium-83/[40 CFR 302.4: U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 21, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 10 curies or 0.37 TBq. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b). /Strontium-85/[40 CFR 302.4: U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 21, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 1000 curies or 37 TBq. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b). /Strontium-85m/[40 CFR 302.4: U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 21, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 100 curies or 3.7 TBq. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b). /Strontium-87m/[40 CFR 302.4: U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 21, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 10 curies or 0.37 TBq. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b). /Strontium-89/[40 CFR 302.4: U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 21, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 0.1 curie or 0.0037 TBq. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b). /Strontium-90/[40 CFR 302.4: U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 21, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 10 curies or 0.37 TBq. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b). /Strontium-91/[40 CFR 302.4: U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 21, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 100 curies or 3.7 TBq. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b). /Strontium-92/[40 CFR 302.4: U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 21, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

ATMOSPHERIC STANDARDS:

Radionuclides have been designated as hazardous air pollutants under section 112 of the Clean Air Act. /Radionuclides/[40 CFR 61.0; U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of November 24, 2005: http://www.gpoaccess.gov/ecfr] **PEER REVIEWED**

STATE DRINKING WATER STANDARDS:

(AL) ALABAMA 8 pCi/L /Strontium-90/[USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93) To Present] **PEER REVIEWED**

(CA) CALIFORNIA 8 pCi/L /Strontium-90/[USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93) To Present] **PEER REVIEWED**

(CT) CONNECTICUT 8 pCi/L /Strontium-90/[USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93) To Present] **PEER REVIEWED**

(IL) ILLINOIS 8 pCi/L /Strontium-90/[USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93) To Present] **PEER REVIEWED**

(NH) NEW HAMPSHIRE 8 pCi/L /Strontium-90/[USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93) To Present] **PEER REVIEWED**

(WI) WISCONSIN 8 pCi/L /Strontium-90/[USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93) To Present] **PEER REVIEWED**

FDA REQUIREMENTS:

21 CFR 1002.20. Accidental Radiation Occurrences documents any actual or possible unexpected exposure during manufacturing, testing, or use of ANY electronic product. Reports are due immediately after the event is known.[21 CFR 1002.20; Food and Drug Administration, Accidental Radiation Occurrences and Radiation Incidents; revised 2005. Available from, as of November 28, 2005: http://www.fda.gov/cdrh/radhlth/eprc_reports_and_records.html] **PEER REVIEWED**

CHEMICAL/PHYSICAL PROPERTIES:

OTHER CHEMICAL/PHYSICAL PROPERTIES:

There are 33 isotopes and isomers of strontium(2). Natural strontium is a mixture of four stable isotopes(1): strontium-84, strontium-86, strontium-87, and strontium-88(2). Strontium-73 through -83, strontium-85, and strontium-89 through -105 are artificially produced and are radioactive(2).[(1) Lide DR; CRC Handbook of Chemistry and Physics. 86th Ed, 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL p 4-35 (2005) (2) Baum EM et al; Nuclides and isotopes. Chart of the nuclides /and/ information booklet. 16th ed. KAPL, Inc. -- distributed by Lockheed Martin. (2002)] **PEER REVIEWED**

The most important chemical properties of the radioactive forms of strontium are similar to those of the stable (non-radioactive) form.[ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

DECAY PATHWAY: Strontium-85, half-life 64.84 days, decays via electron capture (1065 keV) to rubidium-85, half-life stable[IAEA; Live Chart of Nuclides. National Nuclear Data Services. Inter Atomic Energy Agency, Nuclear Data Sect. Vienna, Austria] **PEER REVIEWED**

DECAY PATHWAY: Strontium-89, half-life 50.53 days, decays via beta(-) emission (1495.1 keV) to yttrium-89, half-life stable[IAEA; Live Chart of Nuclides. National Nuclear Data Services. Inter Atomic Energy Agency, Nuclear Data Sect. Vienna, Austria] **PEER REVIEWED**

DECAY PATHWAY: Strontium-90, half-life 28.79 years, decays via beta(-) emission (100%, 546.0 keV maximum; 195.8 keV average energy) to yttrium-90, half-life 64.00 hours; decays via beta (-) emission (99.989%, 2280.1 keV maximum, 933.7 keV average energy) to zirconium-90, half-life stable.[IAEA; Live Chart of Nuclides. National Nuclear Data Services. Inter Atomic Energy Agency, Nuclear Data Sect. Vienna, Austria] **PEER REVIEWED**

DECAY PATHWAY: Strontium-91, half-life 9.63 hrs, decays via beta(-) emission (2707 keV) to yttrium-91, half-life 58.51 days. Yttrium-91 decays via beta(-) emission (1544.8 keV) to zirconium-91, half-life stable[IAEA; Live Chart of Nuclides. National Nuclear Data Services. Inter Atomic Energy Agency, Nuclear Data Sect. Vienna, Austria] **PEER REVIEWED**

DECAY PATHWAY: Strontium-92, half-life 2.71 hrs, decays via beta(-) emission (1940 keV) to yttrium-92, half-life 3.54 hrs. Yttrium-92 decays via beta(-) emission (3639 keV) to zirconium-92, half-life stable[IAEA; Live Chart of Nuclides. National Nuclear Data Services. Inter Atomic Energy Agency, Nuclear Data Sect. Vienna, Austria] **PEER REVIEWED**

Radioactive Half-life: Strontium-85: 64.95 days; Emission Types and Energies: Electron capture energy (1.065 MeV)[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-77] **PEER REVIEWED**

Radioactive Half-life: Strontium-89: 50.52 days; Emission Types and Energies: Beta energy (1.497 MeV)[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-77] **PEER REVIEWED**

Radioactive Half-life: Strontium-90: 29.1 yrs; Emission Types and Energies: Beta energy (0.546 MeV)[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-77] **PEER REVIEWED**

Radioactive Half-life: Strontium-91: 9.5 hours; Emission Types and Energies: Beta energy (2.707 MeV)[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-77] **PEER REVIEWED**

Radioactive Half-life: Strontium-92: 2.71 hours; Emission Types and Energies: Beta energy (1.91 MeV)[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-77] **PEER REVIEWED**

Radioactive forms of strontium are continuously transformed to stable isotopes by the natural process of radioactive decay. Strontium-90 has a radioactive decay half-life of 29 years, while strontium-89 has a much shorter half-life (51 days). Strontium-90 decays by emission of a beta-particle with a maximum energy of 0.546 MeV and the creation of a yttrium-90 isotope, which is also unstable. Yttrium-90 decays by beta-particle and gamma ray emission to the stable zirconium-90 isotope. Strontium-89 decays to yttrium-89 by emission of a negative beta-particle with a maximum energy of 1.495 MeV.[ATSDR; Toxicological Profile for Strontium (Draft for Public Comment). Atlanta, GA: Agency for Toxic Substances and Disease Registry (2001)] **PEER REVIEWED**

Three allotropic forms exist, with transition points at 235 and 540 deg C. ... Natural strontium is a mixture of four isotopes; 32 other unstable isotopes are known to exist.[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 4-35] **PEER REVIEWED**

Strontium exists exclusively in the +2 oxidation state in solution, so the chemistry of strontium is uncomplicated by oxidation-reduction reactions that could produce alternate states in solution.[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-156 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf] **PEER REVIEWED**

COMPLEXATION. Strontium has little tendency to form complexes. Of the few complexing agents for strontium, the significant agents in radiochemistry to date are EDTA, oxalate, citrate, ammoniatriacetate, methylanine-N,N-diacetate, 8-quinolinol, and an insoluble chelate with picrolonate. The most stable complex ion forms with EDTA. Coordination compounds of strontium are not common. These chelating agents are used primarily in ion-exchange procedures. Amine chelates of strontium are unstable, and the beta-diketones and alcohol chelates are poorly characterized. In contrast, cyclic crown ethers and cryptates form stronger chelates with strontium than with calcium, the stronger chelating metal with EDTA and more traditional chelating agents. /Strontium complexes/[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-157 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006:

http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf] **PEER REVIEWED**

CHEMICAL SAFETY & HANDLING:

FIRE FIGHTING PROCEDURES:

Radioactive material that presents a radiological risk: if material on fire or involved in fire, contact the local, state, or Department of Energy Radiological Response Team. Extinguish fire using agent suitable for type of surrounding fire. Cool all affected containers with flooding quantities of water. Apply water from as far a distance as possible.[Association of American Railroads/Bureau of Explosives; Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads. Pueblo, CO. 2002., p. 800] **PEER REVIEWED**

PRIOR HISTORY OF ACCIDENTS:

The Chelyabinsk region of the southern Ural Mountains was one of the main military production centers of the former USSR and included the Mayak nuclear materials production complex in the closed city of Ozersk. Accidents, nuclear waste disposal and day-to-day operation of the Mayak reactor and radiochemical plant contaminated the nearby Techa River. The period of most releases of radioactive material was 1949-56, with a peak in 1950-51. During the first years of the releases, 39 settlements were located along the banks of the Techa River, and the total population was about 28,000. Technical flaws and lack of expertise in radioactive waste management led to contamination of vast areas, and the population was not informed about the releases. The protective measures that were implemented (evacuations, restrictions on the use of flood lands and river water in agricultural production and for domestic purposes) proved to be ineffective, since they were implemented too late. Approximately 7,500 people were evacuated from villages near the River between 1953 and 1960. ... During 1949-56, 7.6x10+7 cubic meters of liquid wastes with a total radioactivity of 100 Pbq were released into the Techa-Isset-Tobol river system. ... Large populations were exposed over long periods to external gamma radiation, due largely to cesium-137 but also to other gamma-emitting radionuclides such as zirconium-95, niobium-95 and ruthenium-106 present in the water and on the banks of the Techa River. The internal radiation dose was from ingestion of strontium-90 and cesium-137 over long periods....Systematic follow up of a cohort of almost 30,000 individuals who received significant exposure from the releases was begun in 1967. ... The preliminary results of follow-up from 1950 through 1989, which were analyzed in linear dose-response models for excess relative risk, indicate an increased rate of mortality from leukemia and solid tumors related to internal and external doses of ionizing radiation.[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. v75 p.154-5 (2000)] **PEER REVIEWED**

PROTECTIVE EQUIPMENT & CLOTHING:

Operations that routinely produce airborne contamination should use engineered containment and ventilation systems to prevent exposures to individuals from air borne releases to the environment....Appropriate personal respiratory protective devices may be used ... but only in abnormal situations or when effective engineering controls are not feasible...For radiation safety, the primary functions of a ventilation system are to move airborne contamination away from occupied work areas (and the potentially exposed workers) and to provide a mechanism for the "recontainment" of the airborne radioactive material that was released. To meet these objectives, the ventilation system must have acceptable pressure differentials between work areas and the outside environment. High-efficiency particulate air (HEPA) filtration or other appropriate filtration may be needed, but the radiation exposure of individuals from the radioactive materials retained on the filter should be evaluated. A pressure differential system should be used to control the flow of airborne contamination. In the system design, a pressure gradient should be established, with the lowest pressure and collection points in areas with the highest potential for release of dispersible material. The flow should always be from clean areas to contaminated areas.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 32-3, (1998)] **PEER REVIEWED**

Shielding may be necessary to reduce the potential for exposures to workers and visitors at the facility and to the public in the vicinity of the facility. ... Vvarious materials can be used for shielding, depending on the type of radiation, its energy and intensity, and the attenuation required.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 30-1, (1998)] **PEER REVIEWED**

Shielding for phosphorus-32 and other beta emitters should be made of material with atomic numbers of < 13 (aluminum) to reduce the generation of Bremsstrahlung X-rays (Braking radiation), electromagnetic radiation produced by the rapid electromagnetic radiation produced by the rapid change of velocity of a fast moving particle as it approaches an atomic nucleus and is deflected. /Beta-emitters/[Goldfrank, L.R. (ed). Goldfrank's Toxicologic Emergencies. 7th Edition McGraw-Hill New York, New York 2002.] **PEER REVIEWED**

In most /emergency/ situations, respiratory protection that is designed to protect responders against chemical or biological agents is likely to offer some degree of respiratory protection in a radiological attack. Concerns about the presence of chemical or biological contaminants will influence the selection of respiratory protection. If used properly, simple face masks provide reasonably good protection against inhaling particulates, and allow sufficient air transfer for working at high breathing rates. If available, high-efficiency particulate air filter masks provide even better protection.[ICRP Publication 96. Protecting People against Radiation Exposure in the Event of a Radiological Attack. Annals of the ICRP 35 (1), 2005] **PEER REVIEWED**

PREVENTIVE MEASURES:

The key to an effective program is the formal delegation of authority to competent staff members. The manager of the radiation safety program ... the Radiation Safety officer should be directly responsible to the highest level of management and should have ready access to all levels of the organization. ... Management should appoint a Radiation Safety Advisory Group...the Radiation Safety Committee. The responsibility of the RSC is to formulate institutional radiation safety policies, review and audit the effectiveness of the radiation safety program, and provide guidance to the RSC on the operational uses of radiation and radioactive materials. The RSC is responsible for advising management concerning radiation safety practices and regulations. This individual should be delegated the authority to supervise the operational radiation safety organization, develop a budget and commit expenditures that are allowed by that budget. ..The RSC is responsible for periodic and special surveillance of activities such as acquiring and disposing of radioactive materials, training in radiation safety practices for facility employees and users, developing and maintaining radiation control and dosimetry records, and authorizing the use of radiation and radioactive materials within the facility. The RSC is also responsible for developing and maintaining a radiation safety manual.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p.

13-4 (1998)] **PEER REVIEWED**

The radiation safety manual should include a comprehensive statement of policy and the principal administrative and program procedures established by the RSC. ... The radiation safety manual should include: (1) management's commitment to proper radiation safety practice (2) description of the RSC, the radiation safety staff, and the radiation safety program (3) specific policy and regulatory requirements (4) specific procedures on how to comply with these requirements.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 15, (1998)] **PEER REVIEWED**

Depending on the complexity of a particular task and the training and experience of the individuals involved, procedures for work that involves radiation or radioactive materials should include the following elements as appropriate: (1) a description of the work that is authorized (2) a description of the potential hazards that will be encountered in performing the work, including potential radiation dose rates, identification of the sources of radioactive material, potential radioactive contamination levels, and the potential for intake of radioactive material (3) the identification of individuals responsible for making sure that the work activities are conducted in accordance with the safety procedure (4) the safety controls and procedural safeguards that are necessary to prevent or limit exposure including requirements for protective clothing, respirator protection, internal and external dosimetry, radiation surveys, worker time and dose limitations, limiting conditions fore either radiation or contamination levels, health physics or radiation safety coverage that is required during the task (5) required worker qualification including any specialized training (6) actions to be followed in the event of an emergency (7) a description of contamination control requirements (8) a description of required training and tasks that should be completed before beginning the task at hand (9) a description of the method for authorizing deviations from the specified procedure (10) references to records and reports to be completed (11) a description of acceptable results and of actions to be taken in response to unsatisfactory results.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 16-7, (1998)] **PEER REVIEWED**

Management should ensure that there is a quality assurance program in place to provide oversight of the radiation safety program. ... Area surveys and personal monitoring are significant aids for determining the adequacy of facility design, operating procedures, and worker training. A high-quality surveillance program depends on the availability fo functioning and calibrated instrumentation. The RSC should expect prompt, accurate and consistent reports of the results of routine area surveys and personal monitoring. These reports can provide an indication of serious inadequacies in the facility procedures and training. ...Routine surveys and personal monitoring are usually done on a regular schedule, but may be relatively infrequent (weekly, monthly or quarterly). For this reason, it is important that supervisors understand their essential role in controlling radiation exposure and in recognizing the implications of changes in operating conditions. This is especially critical when high-dose rate radiation sources are being used.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 18-9, (1998)] **PEER REVIEWED**

The amount and detail of the records that the RSC should maintain has become substantial and their maintenance represents an appreciable portion of the effort of the radiation safety staff. ... Included in the records that should be maintained are those that detail administrative actions that affect the program, report internal and external audits, and record deficiencies and corrective actions. Operating procedures, personal monitoring and survey records, instrument calibration records, waste management records, and records of worker training should be maintained in a readily retrievable form.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 23, (1998)] **PEER REVIEWED**

Organizations should establish radiation safety orientation and training programs that include opportunities for all workers to receive repeat training at appropriate intervals. Radiation safety policies and procedures should be integrated into the overall safety program of the organization. The depth and breadth of training needed varies with the job requirements and responsibilities of each individual. Factors that influence the depth of training include the potential for radiation exposure, complexity of tasks to be performed, degree of supervision...., amount of previous training, and degree to which the trainees will instruct or supervise others. Workers who need specialized radiation safety skills require extensive and ongoing in-depth training. ... Records of training programs presented, course curricula and attendance records should be maintained by management.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 38-9, (1998)] **PEER REVIEWED**

An external radiation exposure control program must be established when there is a possibility for workers to be occupationally exposed or for members of the public to receive exposure from facility operations. ...The formality of the program is clearly a function of the dose level. ... Administrative dose guidelines should be established to reduce the potential for individuals to exceed the recommended dose limits. ... An effective external radiation exposure control program will ensure that doses to occupationally exposed individuals are maintained within administrative dose guidelines and that individual doses are maintained ALARA fo the work performed. ...Engineering controls should be the primary means for controlling external radiation doses. These include distance and shielding, remote handling equipment and interlocks. Administrative controls such as safety procedures, radiation work permits, and radiation monitoring and surveys should be a secondary means for controlling external doses, but are a necessary part of the program.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 42-4, (1998)] **PEER REVIEWED**

/In facilities where radioactive materials are handled/ Radiation surveys should be conducted in areas where the potential exists for exposure to external radiation fields in order to: (1) characterize the radiation field so that it can be properly posted and controlled, (2) provide the information required for planning work activities to maintain the external radiation exposures at levels ALARA, and (3) ensure the prompt discovery of changed radiation fields...[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 51-2, (1998)] **PEER REVIEWED**

/In facilities where radioactive materials are handled/ External radiation dose records should be maintained to demonstrate compliance with dose limits and administrative dose guidelines, and to assist in the evaluation of the effectiveness of the external dose control program. .... In addition, records should be maintained of the external radiation surveys that are performed.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 54-5, (1998)] **PEER REVIEWED**

/In facilities where radioactive materials are handled/ There should be an airborne monitoring program for radioactive materials in those areas where there is a significant potential for airborne contamination. It is not appropriate to use personal monitoring devices to control internal exposures. Thus, continuously operating samplers equipped with continuous detection devices may be needed.[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 66-7, (1998)] **PEER REVIEWED**

Although usually not a significant risk to workers, contamination of facilities, equipment or people occurs in many operations involving radioactive material. Contamination control of routine operations is normally accomplished through containment of the radioactive material in chemical hoods, gloved boxes, hot cells, or the use of area exclusion, protective clothing, etc. ...[National Council on Radiation Protection and Measurements. Report No. 127, Operational Radiation Safety Program p. 56-8, (1998)] **PEER REVIEWED**

The investigation of incidents and accidents must be timely. ... Incident and accident investigations should include a thorough examination of the scene, interviews with the people involved, a review of pertinent records, and a complete and accurate report of the incident or accident and subsequent investigation. The location of the event should be completely surveyed with appropriate instruments as needed to determine and document the radiation levels and the extent of radioactive contamination. Personal monitoring devices should be collected and evaluated, and bioassays should be performed as heeded. An inventory of all radioactive material and waste should be made. Any records or logs that have been maintained should be examined. Workers and others in the area should be interviewed early in the investigation. A photographic record of the area may be important to reconstruct the incident or accident .[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 21, (1998)] **PEER REVIEWED**

SHIPMENT METHODS AND REGULATIONS:

Regulating the safety of ... shipments /of radioactive materials/ is the joint responsibility of the NRC and the Department of Transportation (DOT). The NRC establishes requirements for the design and manufacture of packages for radioactive materials. The DOT regulates the shipments while they are in transit and sets standards for labeling these packages and for smaller quantity packages.[NRC, Citizen's Guide to Nuclear Regulatory Commision Information (2003). Available from, as of November 22, 2005: http://www.nrc.gov/reading-rm/citizen-guide.html] **PEER REVIEWED**

CLEANUP METHODS:

In most cases of contamination of equipment and buildings, a mixture of normal housecleaning methods will remove the material. Vacuum cleaners that can handle wet material and have high-efficiency filters are particularly useful. Some surfaces may require repeated scrubbing and vacuuming before they are free of contamination.[Armed Forces Radiobiology Research Institute. Handbook. Medical Management of Radiological Casualties. 2nd ed. April 2003. pp.72-3 Available from: http://www.afrri.usuhs.mil] **PEER REVIEWED**

Washing off the contaminants can prevent beta skin damage. If practical, /in a radiation event/ the effluent should be sequestered and disposed of appropriately. /Beta Emitters/[Armed Forces Radiobiology Research Institute. Handbook. Medical Management of Radiological Caualties. 2nd ed. April 2003. pp.52 Available from: http://www.afrri.usuhs.mil] **PEER REVIEWED**

In most cases, contamination should be controlled, and removed as soon as possible. The contaminated area or equipment should be marked and posted immediately. Nonessential persons should be moved out of the area until decontamination has been completed. Usually simple cleaning techniques and procedures are adequate for most decontamination tasks. Spills and contaminated areas should be cleaned from the outer region inward to reduce the possibility of further spread of the contamination. After cleaning, the area or equipment should be surveyed to ensure that all the contamination has been removed. National Council on Radiation Protection and Measurements.[NCRP Report No. 127, Operational Radiation Safety Program p. 56-8, (1998)] **PEER REVIEWED**

By decontaminating large pieces of equipment, tools, metal, glassware, and clothing, low-level waste generators are able to reuse or recycle them.[Nuclear Energy Institute: Disposal of Low level Radioactive Wastes Fact Sheet, NEI. Available from, as of November 28, 2005: http://www.nei.org/doc.asp?docid=537] **PEER REVIEWED**

DISPOSAL METHODS:

Low-level radioactive waste (LLW) is a general term for a wide range of wastes. Industries, hospitals, and medical, educational, or research institutions; private or government laboratories; and nuclear fuel cycle facilities (e.g., nuclear power reactors and fuel fabrication plants) using radioactive materials generate low-level wastes as part of their normal operations. These wastes are generated in many physical and chemical forms and levels of contamination.[Health Physics Society, Radiation Terms and Definitions: Low-level Radioactive Waste (2005). Available from, as of November 28, 2005: http://hps.org/publicinformation/radterms/] **PEER REVIEWED**

Nuclear Regulatory Commission regulations separate low-level waste into three classes: A, B, and C. The classification of the waste depends on the concentration, half-life, and types of the various radionuclides it contains. The NRC sets requirements for packaging and disposal of each class of waste. Class A low-level waste contains radionuclides with the lowest concentrations and the shortest half-lives. About 95 percent of all low-level waste is categorized as Class A.[Nuclear Energy Institute: Disposal of Low level Radioactive Wastes Fact Sheet, NEI. Available from, as of November 28, 2005: http://www.nei.org/doc.asp?docid=537] **PEER REVIEWED**

Many radionuclides in low-level waste decay to safe levels within a relatively short time. When wastes are safely stored at their generation sites for a few days to a few years (depending on half-life and available storage space), the radioactivity may be reduced to safe background levels.[Nuclear Energy Institute: Disposal of Low level Radioactive Wastes Fact Sheet, NEI. Available from, as of November 28, 2005: http://www.nei.org/doc.asp?docid=537] **PEER REVIEWED**

The radionuclides in the strongest source category (cobalt-60, strontium-90 and cesium-137) are those with moderate half-lives between about 5 and 30 years. With such high strengths and moderate half-lives these /disused/ sources require isolation for hundreds to thousands of years. After 300 years, cobalt-60 (half-life = 5.3 a), a very important radionuclide in a large number of sources, has decayed to harmless levels ... . However, it can also be seen that none of the strontium-90 or cesium-137 sources in the survey decays to the exemption levels in 300 years and they will thus continue to represent point sources of elevated activity if they are disposed of in a near surface repository, even after the conventional institutional control period. /Strontium-90/[International Atomic Energy Agency; Technical Reports Series No. 436., Disposal Options for Disused Radioactive Sources. p. 7-9. Vienna, Austria, 2005] **PEER REVIEWED**

Simple trenches have been used for many decades for the disposal of short lived low and intermediate level wastes. They are generally considered appropriate only for those wastes that will decay sufficiently in situ within an anticipated period of institutional control (generally between 100 and 300 years) to represent no risk to the public, as determined by safety assessments. ... This option would generally only be available for disposal of disused radioactive sources in countries with existing disposal facilities. /Strontium-90/[International Atomic Energy Agency; Technical Reports Series No. 436. Disposal Options for Disused Radioactive

Sources. p. 19. Vienna, Austria, 2005] **PEER REVIEWED**

Low-level waste disposal occurs at commercially operated low-level waste disposal facilities that must be licensed by either the Nuclear Regulatory Commission or Agreement States. ... There are three existing low-level waste disposal facilities in the United States /Barnwell, SC, Richland, WA, Envirocare in Utah/ that accept ... low-level waste. All are in Agreement States.[Nuclear Regulatory Commission, Low-Level Waste Disposal, NRC. Available from, as of November 28, 2005: http://www.nrc.gov/waste/llw-disposal.html] **PEER REVIEWED**

RADIATION LIMITS & POTENTIAL:

When radionuclides have entered the body, cells and tissues will continue to be exposed to the emitted radiation until the radionuclide has been completely excreted or has fully decayed. Dose limits for occupational exposure are generally derived from the dose of the radionuclide integrated over 50 years after the intake. The committed effective dose for occupational exposure, E(50), is defined as the sum of the products of the committed organ or equivalent doses and the appropriate organ or tissue weighting factors, where '50' indicates the integration time in years after intake. In calculating the E(50), the dose coefficient, i.e. the committed effective dose per unit intake, expressed in Sv/Bq, is frequently used. The recommended upper limit for annual intake of radionuclides is based on a committed annual effective dose of 20 mSv. The annual limit on intake in becquerels can be calculated by dividing this value (0.02 Sv) by the dose coefficient.[IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-PRESENT. (Multivolume work). Available at: http://monographs.iarc.fr/index.php, p. V78 37 (2001)] **PEER REVIEWED**

DECAY PATHWAY: Strontium-85, half-life 64.84 days, decays via electron capture (1.065 MeV) to rubidium-85, half-life stable[Korea Atomic Energy Research Institute. Nuclear Data Evaluation Lab. 2000. Nuclide Table. Available from, as of Apr 27, 2006: http://atom.kaeri.re.kr/ton/] **PEER REVIEWED**

DECAY PATHWAY: Strontium-89, half-life 50.53 days, decays via beta(-) emission (1.495 MeV) to yttrium-89, half-life stable[Korea Atomic Energy Research Institute. Nuclear Data Evaluation Lab. 2000. Nuclide Table. Available from, as of Apr 27, 2006: http://atom.kaeri.re.kr/ton/] **PEER REVIEWED**

DECAY PATHWAY: Strontium-90, half-life 28.74 years, decays via beta(-) emission (100%, 546.0 keV maximum; 195.8 keV average energy) to yttrium-90, half-life 64.10 hours; decays via beta (-) emission (99.989%, 2280.1 keV maximum, 933.7 keV average energy) to zirconium-90, half-life stable.[Korea Atomic Energy Research Institute. Nuclear Data Evaluation Lab. 2000. Nuclide Table. Available from, as of Nov 18, 2005: http://atom.kaeri.re.kr/ton/] **PEER REVIEWED**

DECAY PATHWAY: Strontium-91, half-life 9.63 hrs, decays via beta(-) emission (2.699 MeV) to yttrium-91, half-life 58.51 days; decays via beta() emission (1.544 MeV) to zirconium-91, half-life stable[Korea Atomic Energy Research Institute. Nuclear Data Evaluation Lab. 2000. Nuclide Table. Available from, as of May 2, 2006: http://atom.kaeri.re.kr/ton/] **PEER REVIEWED**

DECAY PATHWAY: Strontium-92, half-life 2.71 hrs, decays via beta(-) emission (1.911 MeV) to yttrium-92, half-life 3.54 hrs; decays via beta(-) emission (3.639 MeV) to zirconium-91, half-life stable[Korea Atomic Energy Research Institute. Nuclear Data Evaluation Lab. 2000. Nuclide Table. Available from, as of May 2, 2006: http://atom.kaeri.re.kr/ton/] **PEER REVIEWED**

QUANTITIES OF NRC LICENSED MATERIAL REQUIRING LABELING RADIONUCLIDE QUANTITY (uCi) Strontium-80 100 Strontium-81 1,000 Strontium-83 100 Strontium-85m 1,000 Strontium-85 100 Strontium-87m 1,000 Strontium-89 10 Strontium-90 0.1 Strontium-91 100 Strontium-92 100 [U.S. Nuclear Regulatory Commission; 10 CFR Appendix C to Part 20--Quantities of Licensed Material Requiring Labeling. Available from, as of October 6, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/part020-appc.html]
PEER REVIEWED

ALI values have been established for individual radionuclides and are presented in Table 1 in Appendix B to PART 20.1001-20.2401. The ALI values for inhalation, presented in Column 2 in Table 1, correspond to a committed effective dose equivalent of 5 rems (0.05 Sv) or a committed dose equivalent of 50 rems (0.5 Sv) to any individual organ or tissue, whichever is more limiting. If the ALI value presented in Table 1 is limited by the 50-rem committed dose equivalent, the controlling organ is listed directly below the ALI value, and the stochastic ALI value based on the 5-rem committed effective dose equivalent is listed in parentheses directly below the organ name. If a stochastic ALI is listed in parentheses, that value should be used to calculate the committed effective dose equivalent.[U.S. Nuclear Regulatory Commission; Regulatory Guide 8.34 - Monitoring Criteria and Methods to Calculate Occupational Radiation Doses. 1992/ Available from, as of September 25, 2006:
http://www.nrc.gov/reading-rm/doc-collections/reg-guides/occupational-health/active/8-34/index.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-80 CLASS ORAL INGESTION ALI (uCi) INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 4E+3 1E+4 5E-6 Y, all insoluble compounds and SrTiO3 - 1E+4 5E-6 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-80.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-81 CLASS ORAL INGESTION ALI (uCi) INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 3E+4 8E+4 3E-5 Y, all insoluble compounds and SrTiO3 2E+4 8E+4 3E-5 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-81.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-82 CLASS ORAL INGESTION ALI (uCi) INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 3E+2 (LLI wall) (2E+2) 4E+2 2E-7 Y, all insoluble compounds and SrTiO3 2E+2 9E+1 4E-8 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-82.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-83 CLASS ORAL INGESTION ALI (uCi)

INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 3E+3 7E+3 3E-6 Y, all insoluble compounds and SrTiO3 2E+3 4E+3 1E-6 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-83.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-85 CLASS ORAL INGESTION ALI (uCi) INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 3E+3 3E+3 1E-6 Y, all insoluble compounds and SrTiO3 - 2E+3 6E-7 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-85.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-85m CLASS ORAL INGESTION ALI (uCi) INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 2E+5 6E+5 3E-4 Y, all insoluble compounds and SrTiO3 - 8E+5 4E-4 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-85m.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-87m CLASS ORAL INGESTION ALI (uCi) INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 5E+4 1E+5 5E-5 Y, all insoluble compounds and SrTiO3 4E+4 2E+5 6E-5 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-87m.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-89 CLASS ORAL INGESTION ALI (uCi) INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 6E+2 (LLI wall) (6E+2) 8E+2 4E-7 Y, all insoluble compounds and SrTiO3 5E+2 1E+2 6E-8 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-89.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-90 CLASS ORAL INGESTION ALI (uCi) INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 3E+1 (Bone Surf) (4E+1) 2E+1 (Bone Surf) (2E+1) 8E-9 Y, all insoluble compounds and SrTiO3 - 4E+0 2E-9 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-90.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-91 CLASS ORAL INGESTION ALI (uCi) INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 2E+3 6E+3 2E-6 Y, all insoluble compounds and SrTiO3 - 4E+3 1E-6 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-91.html]
PEER REVIEWED

OCCUPATIONAL VALUES FOR STRONTIUM-92 CLASS ORAL INGESTION ALI (uCi) INHALATION: ALI (uCi) INHALATION: DAC (uCi/mL) D, all soluble compounds except SrTiO3 3E+3 9E+3 4E-6 Y, all insoluble compounds and SrTiO3 - 7E+3 3E-6 [U.S. Nuclear Regulatory Commission; Table 1, Appendix B to Part 20-Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure. Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-92.html]
PEER REVIEWED

EFFLUENT CONCENTRATIONS ESTABLISHED BY THE NRC FOR SOME STRONTIUM COMPOUNDS RADIONUCLIDE CLASS EFFLUENT CONCENTRATIONS: Air (uCi/mL) EFFLUENT CONCENTRATIONS: Water (uCi/mL) Strontium-80 D, all soluble compounds except SrTiO3 2E-8 6E-5 Y, all insoluble compounds and DrTiO3 2E-8 - Strontium-81 D 1E-7 3E-4 Y 1E-7 - Strontium-82 D 6E-10 3E-6 Y 1E-10 - Strontium-83 D 1E-8 3E-5 Y 5E-9 - Strontium-85 D 4E-9 4E-5 Y 2E-9 - Strontium-85m D 9E-7 3E-3 Y 1E-6 - Strontium-87m D 2E-7 6E-4 Y 2E-7 - Strontium-89 D 1E-9 8E-6 Y 2E-10 - Strontium-90 D 3E-11 5E-7 Y 6E-12 - Strontium-91 D 8E-9 2E-5 Y 5E-9 - Strontium-92 D 1E-8 4E-5 Y 9E-9 - [U.S. Nuclear Regulatory Commission; Table 2, Appendix B to Part 20-Effluent Concentrations Available from, as of October 11, 2006:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Strontium-80.html]
PEER REVIEWED

OCCUPATIONAL EXPOSURE STANDARDS:

THRESHOLD LIMIT VALUES:

The TLV Physical Agents Committee accepts the occupational exposure guidance of the International Commission on Radiological Protection (ICRP). ... ICRP Guidelines for Exposure to Ionizing Radiation: Effective Dose (a) in any single year, 50 mSv, (b) averaged over 5 years, 20 mSv per year. Annual Equivalent Dose to: (a) lens of the eye, 150 mSv, (b) skin, 500 mSv, (c) hands and feet, 500 mSv. Embryo-Fetus exposures once the pregnancy is known - monthly equivalent dose 0.5 mSv - dose to the surface of women's abdomen (lower trunk) 2 mSv for the remainder of the pregnancy - intake of radionuclide one twentieth of Annual Limit on Intake (ALI). /Ionizing radiation/[American Conference of Governmental Industrial Hygienists TLVs and BEIs. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. Cincinnati, OH, 2008, p. 184] **QC REVIEWED**

The TLV Physical Agents Committee accepts the occupational exposure guidance of the International Commission on Radiological Protection (ICRP). Ionizing radiation includes particulate radiation (e.g., alpha particles and beta particles emitted from radioactive materials, and neutrons from nuclear reactors and accelerators) and electromagnetic radiation (e.g., gamma rays emitted from radioactive materials and X-rays from electron accelerators and X-ray machines) with energy greater than

12.4 electron-volts (eV) ... The guiding principle of radiation protection is to avoid all unnecessary exposures. ICRP has established principles of radiological protection. These are (1) the justification of a work practice: No work practice involving exposure to ionizing radiation should be adopted unless it produces sufficient benefit to the exposed individuals or the society to offset the detriment it causes. (2) The optimization of a work practice: All radiation exposures must be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account. (3) The individual dose limits: The radiation dose from all relevant sources should not exceed the /ICRP/ prescribed dose limits. /Ionizing radiation/[American Conference of Governmental Industrial Hygienists TLVs and BEIs. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. Cincinnati, OH, 2008, p. 183] **QC REVIEWED**

OTHER STANDARDS REGULATIONS AND GUIDELINES:

The recommendations in the American National Standards Institute standard, ANSI Z88.2-1992, "American National Standard For Respiratory Protection," are endorsed by the U.S. Nuclear Regulatory Commission and may be used by licensees in establishing a respiratory protection program with the /several/exceptions /including limitations that do not permit or greatly restrict the use of quarter-facepiece respirators and supplied air respirators and self-contained breathing apparatus (SCBA) that operate in the demand mode./[U.S. Nuclear Regulatory Commission; Regulatory Guide 8.15 - Acceptable Programs for Respiratory Protection. October 1999. Available from, as of October 2, 2006: http://www.nrc.gov/reading-rm/doc-collections/reg-guides/occupational-health/active/8-15/index.html]
PEER REVIEWED

Applicability of OSHA's Respiratory Protection Rules: ... if an NRC licensee is using respiratory protection to protect workers against nonradiological hazards, the OSHA requirements apply. If the NRC has jurisdiction and is responsible for inspection, the ... NRC will inform the licensee and OSHA if the NRC observes an unsafe condition relative to nonradiological hazards. In general, ... if a licensee is in compliance with the NRC regulations in Subpart H, the licensee is considered to be in compliance with the corresponding and comparable OSHA regulations on respiratory protection. ... In situations involving mixed hazards, such as airborne radioactive materials and nonradioactive hazardous materials, compliance with 10 CFR Part 20 alone may not provide sufficient protection.[U.S. Nuclear Regulatory Commission; Regulatory Guide 8.15 - Acceptable Programs for Respiratory Protection. October 1999. Available from, as of October 2, 2006: http://www.nrc.gov/reading-rm/doc-collections/reg-guides/occupational-health/active/8-15/index.html]
PEER REVIEWED

This part contains the requirements and provisions for the medical use of byproduct material and for issuance of specific licenses authorizing the medical use of this material. These requirements and provisions provide for the radiation safety of workers, the general public, patients, and human research subjects. The requirements and provisions of this part are in addition to, and not in substitution for, others in this chapter. The requirements and provisions of parts 19, 20, 21, 30, 71, 170, and 171 of this chapter apply to applicants and licensees subject to this part unless specifically exempted. Nothing in this part relieves the licensee from complying with applicable FDA, other Federal, and State requirements governing radioactive drugs or devices.[U.S. Nuclear Regulatory Commission; 10 CFR PART 35--MEDICAL USE OF BYPRODUCT MATERIAL. Available from, as of October 17, 2006: http://www.nrc.gov/reading-rm/doc-collections/cfr/part035/full-text.html]
PEER REVIEWED

/In the U.S./ NUREG-1736, Consolidated Guidance: 10 CFR Part 20 - Standards for Protection Against Radiation, consolidates /NRC/ guidance into a single comprehensive source by reference to numerous guidance documents. It complements the NUREG-1556 series, Consolidated Guidance about Materials Licenses. Since Part 20 applies to all NRC licensees, in varying degrees, it extends beyond the materials scope of NUREG-1556. Each section in this document provides the following:" A statement of the requirement (reflecting revisions published in the Federal Register through October 13, 1999); A discussion of the requirement; A statement of the requirement's applicability; A guidance statement; A list of existing regulatory guidance (Regulatory Guides, NUREG reports); A list of existing implementation guidance (Information Notices, health physics positions, Part 20 questions and answers, etc.). NUREG-1736, Consolidated Guidance: 10 CFR Part 20 - Standards for Protection Against Radiation, also identifies prior guidance that is now outdated and in some cases subject to withdrawal or revision.[Division of Industrial and Medical Nuclear Safety Office of Nuclear Material Safety and Safeguards U.S. Nuclear Regulatory Commission Washington, DC 20555-0001. NUREG-1736, Consolidated Guidance: 10 CFR Part 20 - Standards for Protection Against Radiation. Abstract and availability notice available at [http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1736/index.html#abs] as of July 2006] **PEER REVIEWED**

MANUFACTURING/USE INFORMATION:

MAJOR USES:

Antineoplastic (radiation source) /Sr-89/[Lide, D.R., G.W.A. Milne (eds.). Handbook of Data on Organic Compounds. Volume I. 3rd ed. CRC Press, Inc. Boca Raton ,FL. 1994., p. 1575] **PEER REVIEWED**

The beta emission of strontium-90 and its progeny, yttrium-90, has found applications in industry, medicine, and research. The radiation of yttrium-90 is more penetrating than that of strontium. It is used with zinc sulfide in some luminescent paints. Implants of strontium-90 provide radiation therapy for the treatment of the pituitary gland and breast and nerve tissue. The radiation from strontium has been used in thickness gauges, level measurements, automatic control processes, diffusion studies of seawater, and a source of electrical power. Because strontium-90 is one of the long-lived and most energetic beta emitters, it might prove to be a good source of power in space vehicles, remote weather stations, navigational buoys, and similar long-life, remote devices. Both strontium-89 and strontium-90 have been used in physical chemistry experiments and in biology as tags and tracers. /Strontium isotopes/[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-155 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf] **PEER REVIEWED**

The radioactive isotope Strontium-89 (also known by the pharmaceutical brand name Metastro) is used as a cancer therapeutic to alleviate bone pain. Strontium-85 has been used in medical applications, such as radiologic imagining of bones, in minor commercial applications, such as thermoelectric power generation, as a beta-particle standard source, and in instruments that measure thickness and density of materials. /Strontium-89 and 85/[ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

Radioisotope thermoelectric generators (RTGs) use heat generated by decay of radioactive isotopes to produce electric power. They have no moving parts and can operate for decades without refuelling. They are used as a power supply where frequent maintenance or refuelling is expensive or impractical. Most terrestrial RTGs are fuelled with strontium-90. The largest known RTG was fuelled with 25 PBq of strontium-90. An RTG typically contains about 2 PBq of strontium. ... Strontium sources can have an oxide or titanate form. /Strontium-90/[International Atomic Energy Agency; Technical Reports Series No. 436. Disposal Options for Disused Radioactive Sources. p 6, 13. Vienna, Austria, 2005] **PEER REVIEWED**

If no repositories are available or are likely to become available in the near future, provision can be made for disposal of radioactive sources in facilities specifically designed to accommodate the generally small volume of radioactive sources. ... Near surface shafts and/or boreholes can be considered as alternative or complementary to near surface vaults. These disposal options have the advantages of being economical and also minimizing the probability of human intrusion. ... Shafts or boreholes to depths of several tens of meters or more are relatively simple to construct and can offer an attractive disposal option for small volumes of waste such as radioactive sources. ... Some Member States have developed disposal facilities for radioactive waste in large rock cavities at depths of several tens of meters, generally in hard crystalline rocks such as granite. They are designed to contain short lived low and intermediate level waste. ... This type of containment would be adequate for the disposal of many if not all types of radioactive sources... Deep boreholes with and without engineered barrier systems are particularly suited to the highest activity and long half-life radioactive sources, for which long containment periods are required. For example, strong radium-226 sources could require isolation for 20,000 to 30,000 years. /Strontium-90/[International Atomic Energy Agency; Technical Reports Series No. 436. Disposal Options for Disused Radioactive Sources. p. 17-25. Vienna, Austria, 2005] **PEER REVIEWED**

Used to study bone formation and metabolism /Strontium-85/[NEI; Fact Sheet. Medical and Industrial Uses of Radioactive Materials. April, 2003. Washington, DC: Nuclear Energy Inst. Available from, as of Apr 27, 2006: http://www.nei.org/index.asp?catnum=3&catid=188] **PEER REVIEWED**

Used in survey meters by schools, the military, and emergency management authorities. /Strontium-90/[NEI; Fact Sheet. Medical and Industrial Uses of Radioactive Materials. April, 2003. Washington, DC: Nuclear Energy Inst. Available from, as of Apr 27, 2006: http://www.nei.org/index.asp?catnum=3&catid=188] **PEER REVIEWED**

METHODS OF MANUFACTURING:

Strontium-85 can be produced by irradiation of rubidium-85 with accelerated protons or deuterons.[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-155 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf] **PEER REVIEWED**

Radioactive strontium, strontium-89 and strontium-90, does not occur in nature, but is the direct result of anthropogenic activity. Strontium-89 and strontium-90 are formed during nuclear reactor operations and during nuclear explosions by the nuclear fission of uranium-235, uranium-238, or plutonium-239. /Radioactive strontium/[ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

GENERAL MANUFACTURING INFORMATION:

The only naturally occurring radioactive isotopes of strontium are the result of spontaneous fission of uranium in rocks. Other nuclear reactions and fallout from nuclear weapons test are additional sources of fission products. Strontium-90 is a fission product of uranium-235, along with strontium-89, and short-lived isotopes, strontium-91 to strontium-102. /Strontium-isotopes/[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-155 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006:
http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf]
PEER REVIEWED

Strontium isotopes are some of the principal constituents of radioactive fallout following detonation of nuclear weapons, and they are released in insignificant amounts during normal operations of reactors and fuel reprocessing operations. Their toxicity is higher, however, than that of other fission products, and strontium-90 represent a particular hazard because of its long half-life, energetic beta emission, tendency to contaminate food, especially milk, and high retention in bone structure. /Strontium isotopes/[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-156 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006:
http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf]
PEER REVIEWED

The isotopes of dominant concern for strontium internal dosimetry are strontium-90 and its decay product yttrium-90. ... Most facilities that have strontium may also be expected to have other fission products present, notably cesium-137. /Strontium-90/[Pacific Northwest National Laboratory; HANFORD: Radiation and Health Technology Methods and Models of the Hanford Internal Dosimetry Program. PNNL-MA-860 (2003) Available from, as of October 4, 2006: http://www.pnl.gov/eshs/pub/pnnl860/pnnl860.pdf]
PEER REVIEWED

Nearly all of the strontium-90 generated in the United States is present in spent nuclear reactor fuel rods.[ATSDR; Toxicological Profile for Strontium. Atlanta, GA: Agency for Toxic Substances and Disease Registry, US Public Health Service (2004)] **PEER REVIEWED**

At the end of their useful life, usually 5 to 15 years, sealed radioactive sources that have applications in medicine, industry, and research are defined as spent or disused. However, the residual level of radioactivity in some sources can still be high, representing a significant radiological hazard. If not properly managed and disposed of, such disused radioactive sources pose a potential health hazard to the public for periods, depending on the half-life and activity level of the radionuclides, which may extend to hundreds or thousands of years. ...The wide range of activities makes it convenient to classify radioactive source strengths as weak (< 10 GBq), medium (10 GBq-10TBq) or strong (> 10 TBq). Higher activity and longer half-life sources require a greater degree of isolation. Specifically, sources of particular concern for disposal are high activity sources containing cobalt-60, strontium-90, and cesium-137, as well as long lived radium, americium and plutonium sources. /Strontium-90/[International Atomic Energy Agency; Technical Reports Series No. 436. Disposal Options for Disused Radioactive Sources. p 1-16. Vienna, Austria, 2005] **PEER REVIEWED**

LABORATORY METHODS:

CLINICAL LABORATORY METHODS:

A method has been developed for the rapid isolation and quantitation of strontium-89 and strontium-90 in urine samples. The radiostrontium is concentrated from the bulk urine sample by coprecipitation with calcium phosphate. The precipitate is then wet ashed with nitric acid, and a solution of the resulting residue in 2 M HNO3-0.5 M Al(NO3)3 is passed through an extraction chromatographic column containing a supported crown ether that preferentially retains strontium. Sorbed strontium may then be eluted from the column with either dilute HNO3 or water and counted via liquid scintillation. A new counting scheme that permits quantitation of both strontium-89 and strontium-90 on the same day the separation is performed is described. /Strontium-89 and -90/[Dietz ML et al; Hlth Phys 61(6): 871-7 (1991)] **PEER REVIEWED**

Reverse-phase partition chromatography has been adapted far rapid determination of strontium-90 in large urine samples. A column is prepared containing the ligand, di(2-ethylhexyl) phosphoric acid which is coated onto the inert support, glass micro beads. The yttrium-90 daughter of strontium-90 is selectively absorbed by the column and subsequently eluted. The yttrium-90 is precipitated as the oxalate, beta counted, and the sample activity level obtained by computer data reduction. The chemical recoveries are better than 80%, precision of analysis is better than 5% and no overall bias is observed. The procedure is rapid, large sample sizes can be used for good sensitivity, and decontamination factors are satisfactory. /Strontium-90 and yttrium-90/[Bogen DC; Hlth Phys 14(2): 131-3 (1968)] **PEER REVIEWED**

Method: inductively coupled plasma-mass spectrometry; Sample Preparation: acid digestion; Analyte: strontium; Matrix: bone; Detection Limit: 6 ug/g dry weight. /From table/[DHHS/ATSDR; Toxicological Profile for Strontium p.250 (April 2004). Available from, as of November 23, 2005: http://www.atsdr.cdc.gov/toxprofiles/tp159.html] **PEER REVIEWED**

Method: liquid scintillation counting; Sample Preparation: coprecipitation with calcium phosphate; sample wet ashed with nitric acid; extraction and separation on Crown ether loaded chromatographic column; Analyte: strontium; Matrix: urine; Detection Limit: 7 dpm/L (0.82 Bq/L or 22 pCi/L). /From table; Strontium-89; Strontium-90/[DHHS/ATSDR; Toxicological Profile for Strontium p.250 (April 2004). Available from, as of November 23, 2005: http://www.atsdr.cdc.gov/toxprofiles/tp159.html] **PEER REVIEWED**

Method: liquid scintillation counting; Sample Preparation: wet ashed; precipitation with oxalate; acid dissolution; chemical extraction; Analyte: strontium; Matrix: urine; Detection Limit: 0.6 pCi (22 mBq). /From table; Strontium-89; Strontium-90/[DHHS/ATSDR; Toxicological Profile for Strontium p.250 (April 2004). Available from, as of November 23, 2005: http://www.atsdr.cdc.gov/toxprofiles/tp159.html] **PEER REVIEWED**

Method: beta gas proportional counter; Sample Preparation: acid dissolution; clean-up by coprecipitation and scavenging; Analyte: strontium; Matrix: urine; Detection Limit: not provided. /From table; total radioactive strontium/[DHHS/ATSDR; Toxicological Profile for Strontium p.250 (April 2004). Available from, as of November 23, 2005: http://www.atsdr.cdc.gov/toxprofiles/tp159.html] **PEER REVIEWED**

ANALYTIC LABORATORY METHODS:

Precipitation of strontium nitrate in 80 percent nitric acid has been used to separate stable strontium carrier and strontium-90 from its progeny, yttrium-90Y, and other soluble nitrates (calcium, for example).[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-157 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006:

http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf]
PEER REVIEWED

In recent years, extraction procedures have been developed based on the complexation of strontium cations with crown ethers in 1-octanol. Strontium can be extracted with these mixture from 1 M to 7 M nitric acid solutions.[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-158 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006:
http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf]
PEER REVIEWED

Strontium-90 has been separated from 90Y on an anion-exchange resin pretreated with hydroxide. Strontium is eluted from the column with water, and yttrium is eluted with 1 M hydrochloric acid. The alkaline earths have been separated by anion-exchange column pretreated with dilute ammonium citrate, loading the column with the chloride form of the metals, and eluting with ammonium citrate at pH 7.5.[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-158 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006:
http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf]
PEER REVIEWED

Strontium-90 is determined directly from its beta emission, before yttrium-90 grows in, by beta counting immediately (three to four hours) after it is collected by precipitation. The chemical yield can be determined gravimetrically by the addition of stable strontium, after the separation of calcium. Alternatively, strontium-90 can be measured from the beta emission of yttrium-90 while it reaches secular equilibrium (two to three weeks). The yttrium-90 is separated by solvent extraction and evaporated to dryness or by precipitation, then beta counted. The chemical yield of the yttrium procedure can be determined by adding stable yttrium and determining the yttrium gravimetrically.[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-160 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006:
http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf]
PEER REVIEWED

Strontium-89 has a half-life of 50.5 d and is only present in fresh fission material. If it is present with strontium-90, it can be determined by the difference in activity of combined strontium-89 and strontium-90 (combined or total strontium) and the activity of strontium-90. Total strontium is measured by beta counting immediately after it is collected by precipitation, and strontium-90 is measured by isolating yttrium-90 after ingrowth. Strontium-85 can be used as a tracer for determining the chemical yield of strontium-90 (determined by isolating yttrium-90), but its beta emission interferes with beta counting of total strontium and must be accounted for in the final activity.[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 14-160 NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available from, as of October 12, 2006:
http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf]
PEER REVIEWED

Instrumental neutron activation analysis was used to study contents of 17 chemical elements (calcium, chlorine, cobalt, chromium, cesium, iron, mercury, potassium, magnesium, manganese, sodium, rubidium, antimony, scandium, selenium, strontium, and zinc) in foods within the south and southwest territories of the Kaluga Region that was exposed to radionuclide contamination /fromChernobyl/. The radionuclide contamination ranges up to 15 Ci/km2 there. Flesh and meat products, dairy products, bread, vegetables, legumes, roots, fruits, and mushrooms were analyzed.[Zaichick V; Food Nutr Bul 23 (3 Suppl): 191-4 (2002)] **PEER REVIEWED** <a href="http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12362793" target=new>PubMed Abstract

SPECIAL REFERENCES:

SPECIAL REPORTS:

Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) NUREG-1576, EPA 402-B-04-001B, NTIS PB2004-105421. Available at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/sr1576v2.pdf as of October 12, 2006

Pacific Northwest National Laboratory; HANFORD: Radiation and Health Technology Methods and Models of the Hanford Internal Dosimetry Program. PNNL-MA-860 (2003) Available at http://www.pnl.gov/eshs/pub/pnnl860/pnnl860.pdf as of October 4, 2006

Department of Health and Human Services ATSDR Toxicological Profile for Strontium (2004) Available at http://www.atsdr.cdc.gov/toxprofiles/tp159.html as of October 26, 2006

U.S. Nuclear Regulatory Commission; Regulatory Guide 8.34 - Monitoring Criteria and Methods to Calculate Occupational Radiation Doses. 1992/ Available at http://www.nrc.gov/reading-rm/doc-collections/reg-guides/occupational-health/active/8-34/index.html as of September 25, 2006

Eckerman KF et al; Federal Guidance Report No. 11 Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion (1988) US Environmental Protection Agency EPA-5201/1-88-020. This resource may be accessed through homer.ornl.gov/VLAB/FedGR11.html for use in two ways; the tables may be accessed interactively by making a request for dose information on individual radionuclides for exposure scenarios of interest, or the Preface and Table of Contents may be viewed directly as in the hardcopy document. In addition, a copy of the printed document may be requested from the Dosimetry Research Group via email or obtained directly from EPA at http://www.epa.gov/radiation/federal/techdocs.htm

International Commission on Radiological Protection; ICRP PUBLICATION 66: HUMAN RESPIRATORY TRACT MODEL FOR RADIOLOGICAL PROTECTION, 66 Annals of the ICRP Volume 24/1-3, its accompanying tables in Publication 68 and the various volumes of ICRP Publication 30 address internal dosimetry calculations. According to the ICRP, the next fundamental Recommendations of ICRP are expected to be issued in 2007. As a consequence, dose coefficients for intakes of radionuclides given in Publications 30 and 68 and data for the interpretation of bioassay measurements in Publications 54 and 78 will need to be updated. ICRP also recognizes the need to provide further guidance on the interpretation of bioassay measurements. A Supporting Guidance Document is in preparation, and will provide a significant development from the information given in previous ICRP reports on this topic.

International Atomic Energy Agency; Technical Reports Series No. 436. Disposal Options for Disused Radioactive Sources. Vienna, Austria, 2005

SYNONYMS AND IDENTIFIERS:

RELATED HSDB RECORDS:

7439 [IONIZING RADIATION]

7389 [CESIUM, RADIOACTIVE]

7406 [YTTRIUM, RADIOACTIVE]

6924 [STRONTIUM COMPOUNDS]

2545 [STRONTIUM, ELEMENTAL; 7440-24-6]

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