POLONIUM, RADIOACTIVE

CASRN: NO CAS RN

This record contains information specific for compounds containing polonium and polonium in the zero valence state; all polonium nuclides are radioactive. For general information on radiation, such as transportation, sampling, analytical methods, regulations, and spill clean-up, 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.

For more information, search the NLM HSDB database.

Human Health Effects:

Human Toxicity Excerpts:

/CASE REPORTS/ /Researchers/ summarized changes in the livers of 10 children and four adolescents exposed accidentally to polonium from polonium-beryllium sources. The amounts of polonium deposited in these two groups ranged from 18.5 kBq to over 370 kBq. Transitory changes were observed in liver function, and decreased numbers of leukocytes and platelets was seen during the first few month after exposure. /Polonium-beryllium/

[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. V. 78 396 (2001) Part 2] **PEER REVIEWED**

/EPIDEMIOLOGY STUDIES/ This study represents the largest epidemiologic investigation of humans exposed to the radionuclide polonium-210. In a cohort of 4,402 white males employed by the Mound Facility, during the period when polonium operations were conducted (1944 to 1972), no excess mortality was observed. Among workers initially hired during World War II, mortality was elevated, especially for deaths from all cancers, cancers of the lung, and cancers of the rectum. These adverse health events do not appear related to exposure to polonium-210. Among workers monitored for polonium-210, mortality was significantly less than expected, although more lung cancers were observed than expected. No significant dose-response trends were identified for all causes combined, all cancers combined, or for cause-specific cancers among the polonium-monitored subcohort. /Polonium-210/

[Wiggs LD et al; Health Phys 61 (1): 71-6 (1991)] **PEER REVIEWED** PubMed Abstract

/EPIDEMIOLOGICAL STUDIES/ ... 22,552 workers ... had been employed by the Atomic Weapons Establishment between 1951 and 1982. Among 9,389 workers who had a record of exposure to radiation, only 638 (17%) were monitored for possible internal exposure to polonium. The incidence of cancer of the kidney (three cases) among those monitored for polonium was statistically significantly elevated ($p < 0.05$), with a SMR of 5.8 ... Many workers were monitored for more than one radionuclide, and no internal doses were available to assist in interpreting this finding. /Polonium, 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. V. 78 222 (2001) Vol 2] **PEER REVIEWED**

/EPIDEMIOLOGICAL STUDIES/ ...a cohort of 4,402 white men employed at the Mound Facility (Dayton, Ohio, USA) during the period 1944 to 72, when polonium-210 was processed and Po-Be neutron sources were manufactured / was studied/. Mortality rates were evaluated by two analytical methods: SMRs with external comparison populations and a dose-response analysis with internal comparisons. The death rates of white men in the country as a whole and of white men in Ohio were used to calculate the SMRs. When the rates for all white males in the USA were used, the SMR for death from any cause among 2,181 210-Po-monitored workers was 0.92 (90% CI, 0.85-0.98), and that for death from any cancer was 1.01 (90% CI, 0.87-1.17). The SMRs for specific cancers were not significantly increased. That for kidney cancer (n = 2) was 0.63 (90% CI, 0.11-1.98), and that for all genitourinary disease was not significantly increased (SMR, 1.30; 90% CI, 0.73-2.16). The SMRs based on rates for white males in Ohio were similar. Dose-response analyses were carried out on data for men monitored for polonium by analysis of urinary excretion, according to the model recommended by the ICRP in 1968. Four categories of polonium dose were used: < 10 mSv, 10 to 99.9 mSv, 100 to 999.9 mSv and > or = to 1,000 mSv. In order to assess potential confounding from exposure to external radiation, the cumulative doses of external radiation of persons in the four dose categories were assessed; no significant differences were observed. The mean external doses of radiation in the four categories ranged from 26.5 mSv to 36.1 mSv. Therefore, external ionizing radiation is not important in interpreting the results of the polonium dose-response analyses. The dose-response analyses were limited to the 2,181 monitored persons for whom estimates of polonium-210 dose were available. For two- and five-year latent periods, Mantel-Haenszel relative risks and ungrouped trend statistics were calculated for all causes, all cancers and lymphatic and hematopoietic cancers combined. No significant positive dose-response trends were observed. When a 10-year latency was used, all the cancer-specific trends were negative, except that for cancer of the pancreas, but none of the trends was statistically significant. The results of this study do not support an association between dose of polonium-210 and mortality from any cancer or any specific cancer.(The /IARC/ Working Group noted that a limitation of this analysis is that measured annual doses of polonium were not available. Annual doses were assigned by evenly partitioning the cumulative dose of an individual between the dates of the individual's first and last monitoring assay, which probably resulted in misclassification of doses across person-years. The dosimetry was complex and subject to substantial uncertainty.) /Polonium-210/

[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. V. 78 222 (2001) Part 2] **PEER REVIEWED**

Medical Surveillance:

Of late the complexes of the dithiol group are used to remove polonium-210 from the body. Among them there are 2,3-dimercaptopropanol (BAL),l,2 sodium 2,3-dimercaptopropansulfonat (unithiol),3-6 and sodium 2-(2, 3-dimercaptopropoxi) ethansulfonat (oxathiol). Those compounds bind polonium in a stable soluble complex, easily removable from a body. Oxathiol is the most effective and safe agent among them.

[Parfenov YD et al; Health Phys 26 (2): 199-202 (1974)] **PEER REVIEWED** PubMed Abstract

Probable Routes of Human Exposure:

Since trace amounts of polonium-210 are found in all environmental media(1), the general population is exposed to small amounts of polonium(SRC). The average amount of polonium-210 in the human body is approximately 1X10-9 curie(1) Individuals who smoke may be exposed to increased polonium(SRC); studies have shown that twice as much polonium is found in the ribs of smokers as compared to nonsmokers(1,2). In studies of the lichen-caribou-human food chain near uranium mining operations in northern Saskatchewan, Canada, polonium-210 was found in soft tissues of caribou(3). Consumption of these tissues enhances the transfer of polonium-210 through the lichen-caribou-human food chain(3). Occupational exposure to polonium compounds may also occur to individuals involved in scientific research using polonium or in the manufacture of products containing polonium(SRC).

[(1) Argonne National Laboratory/EVS. Human Health Fact Sheet, August 2005. Polonium. Available at: http://www.ead.anl.gov/pub/doc/polonium.pdf as of Jan 24, 2006. (2) Eisenbud M, Gesell T, eds; Environmental radioactivity. 4th ed. San Diego: Academic Press. pp. 134-200 (1997) (3) Thomas PA, Gates TE; Environ Health Perspect 107: 527-37 (1999)] **PEER REVIEWED**

Body Burden:

The average amount of polonium-210 in the human body is approximately 1X10-9 curie(1). Polonium-210 concentration in various human tissues from Europe, Japan, and the US ranged from 190-370, 410-970, 420-1,200, 40-310, and 2,200-2,900 mBq/kg in lung, liver, kidney, muscle and other tissues, and bone, respectively(2). Polonium-210 concentration in various human tissues from the US were 190, 410-540, 420, 130-220, and 2,900 mBq/kg in lung, liver, kidney, muscle and other tissues, and bone, respectively(2).

[(1) Argonne National Laboratory/EVS. Human Health Fact Sheet, August 2005. Polonium. Available at: http://www.ead.anl.gov/pub/doc/Polonium.pdf as of Jan 24, 2006. (2) UNSCEAR. 2000. Sources and effects of ionizing radiation. UNSCEAR 2000 report. Volume 1. United Nations Scientific Committee on the Effects of Atomic Radiation. Annex B: Exposures from natural radiation sources. Available at: http://www.unscear.org as of Jan 25, 2006.] **PEER REVIEWED**

Average Daily Intake:

Annual intakes of polonium-210 in the diet ranging from 18 to 220 Bq have been reported in Argentina and Japan, respectively(1). An annual polonium-210 intake of 22 Bq was reported in the US(1).

[(1) UNSCEAR. 2000. Sources and effects of ionizing radiation. UNSCEAR 2000 report. Volume 1. United Nations Scientific Committee on the Effects of Atomic Radiation. Available at: http://www.unscear.org as of Jan 25, 2006.] **PEER REVIEWED**

Emergency Medical Treatment:

Emergency Medical Treatment:

EMT Copyright Disclaimer:

The following Overview, *** IONIZING RADIATION ***, is relevant for this HSDB record chemical.

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.

[Rumack BH POISINDEX(R) Information System Micromedex, Inc., Englewood, CO, 2013; CCIS Volume 158, edition expires Nov, 2013. Hall AH & Rumack BH (Eds): TOMES(R) Information System Micromedex, Inc., Englewood, CO, 2013; CCIS Volume 158, edition expires Nov, 2013.] **PEER REVIEWED**

Antidote and Emergency Treatment:
To decontaminate thermal burns of grades II and III from ... /polonium-210,/ tests have combined complexing agents ... solutions of soap (3%) and KMnO4 (potassium permanganate) (1.5%) ... as well as ... 3% soap solution together with subsequent use of 5% unithyol/oxathyol solutions/ ... which promoted greater cleaning of the burn area (up to 95%) but increased polonium-210 body deposition (approximately fivefold). Similar to experiments of wound decontamination using oxathyol/unithyol, the creation of soluble complexes in the polonium-210 contact sites, their intake in the systemic circulation, and subsequent partial deposition in kidneys are the explanations.
[Gusev, I.A., Guskova, A.K., Mettler, F.A. (eds) Medical Management of Radiation Accidents. Second Edition. CRC Press. Boca Raton, FL. 2001, p. 393] **PEER REVIEWED**

... Acid burns contaminated by polonium-210, have confirmed the necessity of washing the injured area with alkaline agents, particularly soap solutions. ... /except in the case of grade II and III thermal burns/
[Gusev, I.A., Guskova, A.K., Mettler, F.A. (eds) Medical Management of Radiation Accidents. Second Edition. CRC Press. Boca Raton, FL. 2001, p. 394] **PEER REVIEWED**

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. Depending on the risk to rescuers, treatment of serious medical problems takes precedence over radiologic concerns. If there is a potential for contamination of rescuers and equipment, appropriate radiation response protocols should be implemented, and rescuers should wear protective clothing and respirators. Note: I the exposure was to electromagnetic radiation only, the victim is not contaminating and does not pose a risk to downstream personnel. 1. Maintain an open airway and assist ventilation if necessary. 2. Treat coma and seizures if they occur. 3. Replace fluid losses from gastroenteritis with iv crystalloid solutions. 4. 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. /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**

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. ... /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**

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**

Animal Toxicity Studies:

Non-Human Toxicity Excerpts:
/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ An unusually high incidence of kidney disease (tubular degeneration and necrosis with fibrous replacement) was observed among 24 beagles injected at about 5 years of age with 116 or 329 kBq radium-226/kg but not among an additional 10 beagles given about 39 kBq radium-226/kg. This radium-226 solution also contained lead-210, bismuth-210, and polonium-210. To determine whether the kidney disease was related to the radiation from radium-226 and its short-lived progeny or to the alpha radiation from polonium-210, 2 beagles about 7 years of age were injected with 451 kBq radium-226/kg of polonium-210 citrate. Measurements of polonium retention in the kidneys of 4 additional beagles given bismuth-210 citrate enabled /the authors/ to model the retention of these emitters in the dog kidney and to estimate the kidney dose from the alpha radiation of polonium-210 following injection of either 226-Ra + 210-Bi + 210-Po or polonium-210 only. Autoradiography revealed that almost equal concentrations of polonium-210 were in the tubular epithelium and-or its basement membrane and in the glomeruli, but very little of the bismuth-210 deposited in kidney tissue was present in the glomeruli. Radiation damage to the kidneys similar to that observed previously in beagles given radium-226 solutions that also contained bismuth-210 and polonium-210 was seen among the beagles given polonium-210 but not in the dogs given purified radium-226. The analysis of these data indicated that the relatively high incidence of kidney disease among the mature beagles injected with radium-226 and its accompanying bismuth-210 and polonium-210 resulted

from alpha irradiation of the kidneys by the substantial amount of polonium-210 that was in the injection solution. /Radium-226 and polonium-210/
[Bruenger FW et al; Radiat Res122 (3): 241-51 (1990)] **PEER REVIEWED** PubMed Abstract

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ Hamster: The relative carcinogenicity of polonium-210 was studied after intratracheal injection of a soluble form, resulting in relatively uniform distribution of radioactivity in the lung, in contrast to the non-uniform distribution of polonium-210 adsorbed onto Fe2O3 carrier particles. Female Syrian golden hamsters, eight weeks of age, received multiple intratracheal instillations of polonium-210 and/or other materials, as described below, and were observed for life. In the first study, the hamsters were divided into three groups that received two instillations every week for seven weeks. Group 1 received separate instillations of polonium-210 alone and Fe2O3 (3 mg); group 2 received an instillation of polonium-210 plus Fe2O3 (3 mg) and an instillation of saline; and group 3 received the same treatment as group 2, except that the polonium-210 was adsorbed onto 0.3 mg Fe2O3. The doses given to these animals were calculated from data on distribution and retention in hamsters that were killed periodically. In each group, 34 to 38 hamsters were examined histologically. The doses and lung tumor incidences in the three groups were: group 1, 1,500 rad (15 Gy), 22 of 38; group 2, 2,700 rad (27 Gy), 24 of 37; and group 3, 1,700 rad (17 Gy), 15 of 34. The ultimate tumor incidence was not significantly different between groups 1 and 2, but the incidence in group 3 was slightly lower. These experiments at relatively high doses showed that hot spot radiation is not more carcinogenic than a diffuse pattern of alpha-particles when the absorbed dose is taken into account. /Polonium-210/
[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. V. 78 251-2 (2001) Part 2] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ This point was examined further in an experiment with larger numbers of hamsters and lower doses. One group received polonium-210 in saline, another received polonium-210 on Fe2O3 (3 mg) particles, and the controls were either instilled with Fe2O3 or unexposed. The polonium-210 was given as 15 weekly instillations of 1.25 nCi (46 Bq) each. Necropsy of 99 animals that received polonium-210 in saline, resulting in an average dose to the lung of 55 rad (0.55 Gy), showed nine lung tumors. With the combined 210Po-Fe2O3 treatment, the alpha-particle dose was 75 rad (0.75 Gy), and the lung tumor incidence was 10 of 82. The authors found no evidence to support the hot particle hypothesis in these studies. They did note a difference in the histological features of the lung cancers in the two studies: most of the tumors found at the high dose were classified as combined epidermoid and adenocarcinomas because both histological features were often present in the same tumor, whereas all the tumors found at the low dose were combined tumors. (The /IARC/ Working Group noted that these results raise an important, unexplained point: why high incidences of lung tumors were produced in hamsters by intratracheal instillation of polonium-210, while hamsters exposed by inhalation to aerosols of the alpha-particle emitter 239-PuO2 or the beta-particle emitter cerium-144 with fused aluminosilicate particles developed few lung tumors). /Polonium-210/
[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. V 78 252 (2001) Part 2] **PEER REVIEWED**

/LABORATORY ANIMALS: Chronic Exposure or Carcinogenicity/ The same group studied intratracheal instillation of polonium-210 and benzo(a)pyrene into male Syrian golden hamsters from 11 weeks of age in order to examine the possible synergistic effects of combined exposures to these two compounds, both of which are present in tobacco smoke. Various exposure strategies were used, including simultaneous administration of the two agents and sequential administration of one agent before the other. In preliminary studies of simultaneous administration, an additive but not a synergistic lung cancer response was seen. In the study of sequential administration, 312 hamsters each received a single intratracheal instillation of 40 nCi of polonium-210 (1480 Bq) either in saline or on Fe2O3 particles at 11 weeks of age. Eighteen weeks later, half of the animals were given a series of seven weekly intratracheal instillations of 0.3 mg benzo[a]pyrene adsorbed on 3 mg Fe2O3 carrier particles. No lung tumours occurred in 65 animals given polonium-210 alone on Fe2O3 particles and one occurred in 74 animals given polonium-210 in 0.9% saline. Addition of the seven instillations of benzo[a]- pyrene raised these numbers to 13 of 72 and 10 of 63 /with/ tumors, respectively, which the authors interpreted as a synergistic effect. Subsequent studies showed that multiple instillations of 0.9% saline alone could also significantly increase the number of polonium-210 induced lung tumors, even when no chemical carcinogen was present. The authors suggested that their results showed a minimal interaction between polonium-210 and benzo[a]- pyrene. The effect of repeated saline injections after instillations of polonium-210 was considered to mimic the effect of chronic lung irritation, such as might be produced by cigarette smoke acting as a potentiating factor. /Polonium-210 and benzo(a)pyrene/
[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. V. 78 252 (2001) Part 2] **PEER REVIEWED**

/ALTERNATIVE IN VITRO TESTS/ Rat tracheal epithelial cells exhibited exponential cell killing when exposed to polonium-210 alpha particles as single cell suspensions or in the intact tissue. Survival of cells in the intact tissue was not significantly different from that observed with cell suspensions. Comparison of survival of cells exposed in suspension to 300 kVp X rays yielded an RBE of 6.3. Measurements of basal cell nuclei were used to determine that a single traversal of a cell nucleus had a high probability of causing cell inactivation. This was also observed in mink lung cells and CHO cells exposed in an identical manner. There were no significant increases in frequencies of preneoplastic transformation observed for a range of exposures (0.0007 to 0.05 alpha particles/micron). Examination of intact tracheal transplants which were irradiated with alpha particles also failed to reveal any preneoplastic or neoplastic changes. /Polonium-210/
[Ford JR and Terzaghi-Howe M; Radiat Res136 (1): 89-96 (1993)] **PEER REVIEWED** PubMed Abstract

/ALTERNATIVE IN VITRO TESTS/ Alpha-radiation from polonium-210 can elevate background radiation dose by an order of magnitude in people consuming large quantities of meat and seafood, particularly caribou and reindeer. Because up to 50% of the ingested polonium-210 Po body burden is initially found in the blood, a primary target for the short range alpha-particles is the endothelial cells lining the blood vessels. This study examined the relative biological effectiveness (RBE) of polonium-210 alpha-particles versus 250 kVp X-rays in producing injury to cultured bovine aortic endothelial cells... Radiation effects on cells were measured in four different ways: the percentage viable cells by trypan blue dye exclusion, the number of live cells, the lactate dehydrogenase (LDH) release to medium and the ability to form colonies (clonogenic survival)... Comparison of dose-response curves yielded RBE values of 13.1+/-2.5 (SEM) for cell viability, 10.3+/-1.0 for live cell number and 11.1+/-3.0 for LDH activity. The RBE values for clonogenic survival were 14.0+/-1.0 based on the ratio of the initial slopes of the dose-response curves and 13.1, 9.9 and 7.7 for 50, 10 and 1% survival rate, respectively. At X-ray doses <0.25 Gy, a pronounced stimulatory effect on proliferation was noted... Exposure to polonium-210 alpha-particles was seven to 14 times more effective than X-ray exposure in causing endothelial cell damage. /Polonium-210/
[Thomas, PA et al; Int J Radiat Biol 79 (2):107-18 (2003)] **PEER REVIEWED** PubMed Abstract

Metabolism/Pharmacokinetics:

Absorption, Distribution & Excretion:
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, modelling approaches are examined, concentrating on models developed for iodine, caesium, 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**

The gastrointestinal (GI) absorption factors and the biological retention times for polonium were determined for a group of 14 volunteers--seven men and seven women--from Saskatoon, Saskatchewan, Canada. Each volunteer consumed 2.0 kg of caribou meat containing known amounts of naturally occurring polonium-210. Urine and fecal samples were collected for up to 65 days after meat consumption and analysed for polonium-210. The average GI absorption factor for the 14 volunteers was 56 + or - 4% (range = 31 to 71%), not significantly different from the ICRP value of 50%. About 3% of absorbed polonium underwent prompt excretion by the urinary pathway. The remainder was retained by the body with a half-time >100 days, compared to the ICRP value of 50 days. The effect of these findings increases the dose estimate for ingestion of polonium-210 in food by a factor of 1.5 to 3.5. Thus, background doses to people consuming caribou and reindeer may be higher than previously thought. /Polonium-210/
[Thomas PA et al; Radiat Prot Dosimetry 97 (3): 241-50 (2001)] **PEER REVIEWED** PubMed Abstract

Inhalation: Studies of the absorption of polonium in humans after inhalation of a polonium-210 source, which probably comprised small oxide particles, and after inhalation of polonium-210 in tobacco smoke, indicated intermediate solubility. Studies in rats have also shown intermediate solubility after intratracheal instillation of polonium-210 chloride in a sodium chloride aerosol. Similar treatment of rabbits with a polonium-210 hydroxide colloid confirmed these results. /Polonium-210 compounds/
[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. V. 78 345 (2001) Part 2] **PEER REVIEWED**

Ingestion: ICRP reviewed the studies in humans, including a measurement of polonium uptake in a patient being treated for chronic myelogenous leukemia. The blood concentrations and urinary excretion after oral administration of polonium-210 chloride suggested a fractional absorption of 0.1. Absorption of biologically incorporated polonium-210 was reported to be significantly higher, as studies of persons who ate meat from reindeer exposed to polonium-210 indicated a fractional absorption of 0.3 to 0.5. In a study in six volunteers of the absorption of polonium-210 from crabmeat, theabsorbed fraction was estimated to be about 0.8. The absorption of polonium-210 by rats was reported to be 0.03 to 0.06 for an unspecified chemical form and 0.06 for the chloride. In rats, the fractional absorption was 0.05 for polonium-210 administered as the nitrate and 0.13 for polonium-210 incorporated into liver obtained from rats given intravenous injections of polonium-210 citrate. For polonium-210 administered as the citrate, absorption was reported to be 0.07 to 0.09 in adult rats and guinea-pigs. /Polonium chloride and 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. V. 78 345 (2001) Part 2] **PEER REVIEWED**

Systemic distribution, retention and excretion: ... Although polonium belongs to Group VI of the periodic table, with sulfur and selenium, it is more metallic than either of the latter two elements and does not appear to be incorporated into organic compounds, such as the amino acids methionine and selenomethionine. There is a large body of information on the biodistribution and biokinetics of polonium in animals and a considerable amount of data on the biokinetics in humans after inhalation and ingestion of polonium-210. In rabbits injected with polonium-210 nitrate, the main organ of deposition was the kidney (1.3 to 1.5%/g), followed by the blood, spleen, lung and liver; uptake in the skeleton was relatively low (< 0.01%/g...). Polonium appears to be lost from the body relatively rapidly, predominantly in the urine. /Polonium-210 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. V. 78 346 (2001) Part 2] **PEER REVIEWED**

Recent measurements of natural radioactivity in human bone using alpha particle autoradiography have indicated that the alpha activity concentration in the bone marrow is similar to that found in the calcified bone. This paper describes radiochemical measurements made on the calcified bone and the associated bone marrow from three human femurs. A technique was developed to separate and analyze these tissues for the principal naturally-occurring alpha emitter, polonium-210. In all cases the activity concentration of the calcified bone was greater than that of the associated bone marrow. As predicted by the metabolic models used by International Commission on Radiological Protection, the majority of the polonium-210 in whole bone was found to be in the calcified region. /Polonium-210/
[Bradley EJ; Sci Total Environ 130-131: 85-93 (1993)] **PEER REVIEWED**

The gastrointestinal absorption of polonium-210 was determined by comparing tissue retention after oral and systemic administration. The results indicate an increase in absorption in adult rats for polonium-210 administered in liver compared with polonium-210 nitrate with estimated absorption of 5 and 13%, respectively. For polonium-210 citrate, values of about 7% were obtained in 1-day-old neonate and adult rats while absorption in guinea pigs was estimated to be about 23% in 1-day-old neonates, 17% in 5-day-old neonates, and 9% in adults. Gut retention of ingested polonium-210 in neonates was high in rats but not guinea pigs. In adult animals, but not neonates, the liver accounted for a greater proportion of polonium-210 reaching the bloodstream after ingestion than after systemic injection. The significance of these results is discussed in relation to current assumptions made in the calculation of doses from polonium-210. /Polonium-210/
[Haines JW et al; Int J Radiat Biol 64 (1):127-32 (1993)] **PEER REVIEWED** PubMed Abstract

Principal deposition sites (% entering blood) Liver (~30%), kidney (10%), red bone marrow (10%) /from table/ /Polonium/
[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. V. 78 65 (2001) Part 2] **PEER REVIEWED**

The technique of alpha-particle spectroscopy by CR-39 type TASTRAK plastic has been used to study the depth distribution of natural alpha-particle emitters at the surface of human bone. The predominant component of this alpha-particle activity was polonium-210 supported by lead-210, although a smaller activity of radium-226 was also detected. Autopsy samples of human femur and cranium were obtained from subjects age 63 to 86. Both cortical and trabecular surfaces were analyzed. The results indicate that lead-210-supported polonium-210 is concentrated at the surfaces of human bone from elderly subjects, in a narrow band 3 microns deep or less, by a factor of about four. As a result, the alpha-particle dose to the nuclei of cells lining bone surfaces is around 1.8 times greater than that calculated for a uniform volume distribution. Polonium-210 activity indicates the distribution of lead-210, and of stable lead, received by continuous intake throughout life at a very low level. A persistent bone surface concentration of lead and other osteotropic metals may be associated with the hypermineralized layer about 1 micron thick which occurs at the surface of resting bone mineral. /Polonium-210, lead-210, radium-226/
[Salmon PL et al; Radiat Res140 (1): 63-71 1994] **PEER REVIEWED**

The absorption of polonium-210 by rats was reported to be 0.03-0.06 for an unspecified chemical form and 0.06 for the chloride. In rats, the fractional absorption was 0.05 for polonium-210 administered as the nitrate and 0.13 for polonium-210 incorporated into liver obtained from rats given intravenous injections of polonium-210 citrate. For polonium-210 administered as the citrate, absorption was reported to be 0.07-0.09 in adult rats and guinea-pigs. /Polonium compounds/
[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. V.78 345-6 (2001) Part 2] **PEER REVIEWED**

A study of the retention of polonium-210 in marmoset tissues one week after intravenous injection as the citrate showed that the liver accounted for 26% of total body retention; the kidneys retained 21%, and <1% was retained in the spleen and testes. The femora contained 1.5% of the retained activity, corresponding to a skeletal deposit of about 15%. Autoradiographs of marmoset and rat bone showed that the retained polonium-210 was not associated with bone surfaces but was distributed throughout the bone marrow. /Polonium-210 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. V. 78 346 (2001) Part 2] **PEER REVIEWED**

Placental transfer: The fetal transfer of polonium has been studied mainly in rodents and baboons, showing low transfer of polonium to the fetus. These results are in accord with the limited data on humans. Accumulation of polonium-210 in the yolk sac and placenta of rats and guinea-pigs was demonstrated autoradiographically after administration of polonium-210 citrate on various days during gestation. Seven days after intravenous injection of polonium-210 citrate to two baboons in late pregnancy (five months after conception), the retention in the fetus was about 1% of the injected activity. The concentrations in fetal and maternal bone were similar (fetus:mother, 0.6 to 0.7), but those in fetal liver, kidneys and spleen were an order of magnitude lower than the corresponding values for maternal tissues. The overall fetal:maternal concentration ratio was estimated to be 0.3. /Polonium-219 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. V. 78 346-7 (2001) Part 2] **PEER REVIEWED**

Elevated concentrations of polonium-210 were reported in placentae of women in northern Canada who ate reindeer and caribou meat. /Polonium-210/
[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. V. 79 347 (2001) Part 2] **PEER REVIEWED**

Alpha particle energy spectra were measured at femoral endosteal surfaces of Canadian Arctic caribou (Rangifer tarandus). Femur samples from five caribou all showed a pronounced superficial concentration of polonium-210, in a layer 1.9-6.4 microns thick. Within this layer polonium-210 was concentrated 1.5 to 10 times with respect to diffuse volume-distributed polonium-210. This result is consistent with an earlier study of polonium-210 at human cranial bone surfaces, which showed polonium-210 to be concentrated about four times in a surface layer <3 microns thick. However, the present results have higher precision than the human bone data. ... As a result of the measured endosteal superficial concentration of polonium-210 in caribou, the alpha particle dose was calculated to be enhanced by a factor of 1.06 to 1.96 (mean 1.48) for bone lining cells, and of 1.08 to 2.39 (mean 1.69) for soft tissue above the bone surface... /Polonium-210/
[Salmon PL et al; Int J Radiat Biol 68(6): 655-61 (1995)] **PEER REVIEWED** PubMed Abstract

/Spleen/ is the organ receiving the highest /polonium-210/ radiation dose /by inhalation/. /Polonium-210, from table/
[Zenz, C., O.B. Dickerson, E.P. Horvath. Occupational Medicine. 3rd ed. St. Louis, MO., 1994, p. 422] **PEER REVIEWED**

Transfer of polonium-210 to the fetus measured 3 days after administration in rat and 7 days later in guinea pig increased with increasing gestational age to about 0.1% injected activity per rat fetus at birth and 0.6% per guinea pig fetus on day 57, corresponding to whole-body fetus: mother concentration ratios of about 0.1:1 in both species. The greatest concentrations of polonium-210 were measured in the rat yolk sac during its hemopoietic stage, an order of magnitude greater than concentrations in the placenta and two orders of magnitude greater than fetal concentrations. The results obtained have been used to estimate in utero doses to hemopoietic tissues, taking account of transfer to the blastocyst/egg cylinder, yolk sac, liver and bone marrow. The concentration ratios relative to maternal liver for these tissues were taken to be 1, 3, 0.1 and 0.05 respectively and were applied to periods of human gestation of 0 to 2.5, 2.5 to 6, 6 to 12 and 12 to 38 weeks respectively. For chronic maternal intake by ingestion of 210Po during the year of pregnancy giving a committed effective dose (CED) to the mother of 1 mSv, the total in utero dose to hemopoietic tissue was about 340 microSv compared with a maternal red bone marrow dose of 2.2 mSv. The yolk sac and bone marrow accounted for 66 and 27% of the in utero dose respectively. In addition, the total CED to the offspring was calculated assuming a whole-body

fetus: mother concentration ratio of 0.1:1 and that the distribution of polonium-210 between tissues was the same in the foetus as in adults and children. For chronic intake of polonium-210 during the year of pregnancy as assumed above, the CED to the offspring was estimated to be 8% of that to the mother. /Polonium-210/
[Haines JW et al; Int J Radiat Biol 67 (3): 381-90 (1995)] **PEER REVIEWED** PubMed Abstract

Polonium-210 resorption rates for intact ... skin of rats (relating to the applied amount, %); /at/ 1 hour 0.0; 4 hours 0.0; 24 hours 0.013+/- 0.004. /from table/
[Gusev, I.A., Guskova, A.K., Mettler, F.A. (eds) Medical Management of Radiation Accidents. Second Edition. CRC Press. Boca Raton, FL. 2001, p. 372] **PEER REVIEWED**

Polonium-210 resorption rates for ... injured skin of rats (relating to the applied amount, %); /stab wounds at/ 1 hour 5.21 +/- 2.05; 4 hours 8.1 +/- 1.1; 24 hours 25.9 +/- 3.70. /from table/
[Gusev, I.A., Guskova, A.K., Mettler, F.A. (eds) Medical Management of Radiation Accidents. Second Edition. CRC Press. Boca Raton, FL. 2001, p. 372] **PEER REVIEWED**

Polonium-210 resorption rates for ... injured skin of rats (relating to the applied amount, %); /cutaneous muscular wounds at/ 1 hour 0.31 +/- 0.06; 4 hours 2.45 +/- 1.1; 24 hours 9.9 +/- 2.5. /from table/
[Gusev, I.A., Guskova, A.K., Mettler, F.A. (eds) Medical Management of Radiation Accidents. Second Edition. CRC Press. Boca Raton, FL. 2001, p. 372] **PEER REVIEWED**

Polonium-210 resorption rates for ... injured skin of rats (relating to the applied amount, %); /abrasion injury at/ 1 hour 0.13 +/- 0.07; 4 hours 0.21 +/- 0.08; 24 hours 0.56 +/- 0.25. /from table/
[Gusev, I.A., Guskova, A.K., Mettler, F.A. (eds) Medical Management of Radiation Accidents. Second Edition. CRC Press. Boca Raton, FL. 2001, p. 372] **PEER REVIEWED**

The biokinetics of polonium in nonhuman primates (Papio anubis) has been studied after intravenous injection of polonium-210 citrate. The urinary excretion of polonium in the baboon could be described by a single exponential function with a half-time of 15.6 days. Excretion fractions of polonium were found to be markedly different from those reported for other species, including humans. Polonium-210 was found to be distributed throughout the soft tissues of the baboon with 29% of the injected polonium being deposited in liver, 7% in kidneys and 0.6% in spleen. Retention of polonium in all tissues exhibited single exponential functions; however, the biological half-times were variable, ranging from 15 to 50 days. /Polonium-210 citrate/
[Fellman A et al; Radiat Res137 (2): 238-50 (1994)] **PEER REVIEWED** PubMed Abstract

If early surgery /to exposed area/ (at 1 hour) was tried, polonium-210 burdens were strongly decreased in the body (95%) and kidneys (82%) when compared with control animals. /Polonium-210/
[Gusev, I.A., Guskova, A.K., Mettler, F.A. (eds) Medical Management of Radiation Accidents. Second Edition. CRC Press. Boca Raton, FL. 2001, p. 393] **PEER REVIEWED**

Polonium-210 was given subcutaneously to rats and found to be incorporated into liver metallothionein as judged by a number of criteria including heat stability, acetone precipitation, and chromatography. In vitro studies confirmed this binding
[Aposhian HV and Bruce DC; Radiat Res126 (3): 379-82 (1991)] **PEER REVIEWED** PubMed Abstract

Biological Half-Life:
The biokinetics of polonium in nonhuman primates (Papio anubis) has been studied after intravenous injection of polonium-210 citrate. The urinary excretion of polonium in the baboon could be described by a single exponential function with a half-time of 15.6 days. /Polonium-210 citrate/
[Fellman A et al; Radiat Res137 (2): 238-50 (1994)] **PEER REVIEWED** PubMed Abstract

Retention half-time ~50 days /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. V. 78 65 (2001) Part 2] **PEER REVIEWED**

Analysis of the data on human excretion suggested that the half-time of whole-body retention of polonium-210 ranges from 30 to 50 days. Two studies of polonium-210 retention in children aged 6 to 15 years showed a half-time of about 40 days, which is not significantly different from the values for adults. /Polonium-210/
[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. V. 78 346 (2001) Part 2] **PEER REVIEWED**

The commonest natural isotope of polonium, polonium-210, has a half-life of 138.4 days and has an effective biological half-time of 46 days. /Polonium-210/
[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. V. 78 222 (2001) Part 2] **PEER REVIEWED**

Interactions:
Polonium-210 is one of the most hazardous radionuclides. As recently as 1988, there have been concerns regarding accidental exposures of humans to it. Yet, there have been no studies on the effectiveness of the newer dithiol chelating agents in increasing the excretion of this radioactive heavy metal. In order to accomplish this, a safe and effective method for determining the radioactivity of polonium-210, an alpha emitter, in the feces was developed. The excretion of polonium-210 was studied by giving male Sprague-Dawley rats 210Po (3.33x10+7) cpm/kg, intraperitoneal); 1 hr later they were given either 5% sodium bicarbonate, N-(2,3-dimercaptopropyl)phthalamidic acid (DMPA) or meso-dimercaptosuccinic acid (DMSA) (0.20 mmol/kg, subcutaneous). Treatment was repeated daily for 12 days. DMPA and DMSA increased the urinary excretion of polonium-210, as compared to control animals, 8-fold and 5-fold, respectively. DMPA increased the fecal excretion of polonium-210 compared to the other treatments and also decreased the level of polonium-210 in the spleen, a radiosensitive organ. DMPA (0.20 mmol/kg, intravenous) increased biliary levels of polonium-210 5-fold compared to controls. The results indicate that DMPA has greater specificity in chelating and increasing the excretion of polonium-210 than DMSA. /Polonium-210 and chelating agents/
[Bogdan GM, Aposhian HV; Biol Met 3 (3-4): 232-6 (1990)] **PEER REVIEWED** PubMed Abstract

The same group studied intratracheal instillation of polonium-210 and benzo(a)pyrene into male Syrian golden hamsters from 11 weeks of age in order to examine the possible synergistic effects of combined exposures to these two compounds, both of which are present in tobacco smoke. Various exposure strategies were used, including simultaneous administration of the two agents and sequential administration of one agent before the other. In preliminary studies of simultaneous administration, an additive but not a synergistic lung cancer response was seen. In the study of sequential administration, 312 hamsters each received a single intratracheal instillation of 40 nCi of polonium-210 (1,480 Bq) either in saline or on Fe2O3 particles at 11 weeks of age. Eighteen weeks later, half of the animals were given a series of seven weekly intratracheal instillations of 0.3 mg benzo[a]pyrene adsorbed on 3 mg Fe2O3 carrier particles. No lung tumours occurred in 65 animals given polonium-210 alone on Fe2O3 particles and one occurred in 74 animals given polonium-210 in 0.9% saline. Addition of the seven instillations of benzo[a]-pyrene raised these numbers to 13 of 72 and 10 of 63 /with/ tumors, respectively, which the authors interpreted as a synergistic effect. Subsequent studies showed that multiple instillations of 0.9% saline alone could also significantly increase the number of polonium-210 induced lung tumors, even when no chemical carcinogen was present. The authors suggested that their results showed a minimal interaction between polonium-210 and benzo[a]- pyrene. The effect of repeated saline injections after instillations of polonium-210 was considered to mimic the effect of chronic lung irritation, such as might be produced by cigarette smoke acting as a potentiating factor. /Polonium-210 and benzo(a)pyrene/
[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. V. 78 252 (2001) Part 2] **PEER REVIEWED**

Contaminated puncture wounds were simulated in rat by intramuscular injection of polonium-210. The aim of the study was to determine the effectiveness of chelation treatment as a function of time, dosage, and route of chelate administration. Ten newly synthesized substances containing vicinal sulfhydryl and carbodithioate groups were used and their effect was compared with that of chelators clinically applicable in man, BAL (2,3-dimercaptopropane-1-ol), DMPS (2,3-dimercaptopropane-1-sulfonate), DMSA (meso-2,3-dimercaptosuccinic acid), and DDTC (sodium diethylamine-N-carbodithioate). The results indicate first that complete removal of polonium-210 from the injection site is achieved by only two local injections of DMPS, beginning as late as 2 hr after injection of polonium-210. Second, many of the substances used merely induce translocation of polonium-210 from the injection site into other tissues. Third, a combined local treatment at the injection site with DMPS plus repeated systemic, subcutaneous, treatments with HOEtTTC (N,N'-di-(2-hydroxyethyl)ethylenediamine-N,N-biscarbodithioate), a derivative of DDTC, results after 2 weeks in a reduction of the estimated total body retention of polonium-210 to about one-third of that in untreated controls. In the latter case the cumulative excretion of polonium-210 increased from 8 to 54%, mainly via the feces. /Polonium-210 and chelating agents/
[Volf V et al; Int J Radiat Biol 68 (4): 395-404 (1995)] **PEER REVIEWED** PubMed Abstract

Repeated subcutaneous chelation was conducted after intravenous injection of polonium-210 nitrate /to rats/. For reduction of polonium-210 retention the treatment with vicinal dithiols meso-and rac-2,3-dimercaptosuccinic acid (DMSA), mono-i-amylmeso-2,3-dimercapto succinate (Mi-ADMS) and mono-N-(i-butyl)-meso-2,3-dimercapto succinamide (Mi-BDMA) were used. For the reduction of toxic effects of polonium-210, treatment effectiveness of Mi-BDMA was compared with that of N,N'-di(2-hydroxyethyl)ethylenediamine-N,N'-biscarbodithioate (HOEtTTC, reference compound). ... Treatment with meso-DMSA and rac-DMSA altered

the main excretion route of polonium-210, reduced its contents in the liver but increased its deposition in the kidneys. Treatment with Mi-ADMS or Mi-BDMA increased total excretion of polonium-210, mainly via the feces. Only Mi-BDMA decreased polonium-210 levels in the kidneys. The effectiveness of all chelators decreased with delay in the start of treatment. In a survival study, the lives of rats treated early with Mi-BDMA or delayed with HOEtTTC were prolonged three-fold when compared with rats receiving a lethal amount of polonium-210 only. ... Of the vicinal dithiols examined, Mi-BDMA was the best mobilizing chelating agent for polonium-210 and it reduced polonium-210 toxicity when the treatment started immediately. However, the detoxification efficacy of the immediate treatment with HOEtTTC, observed in our previous study, was superior to that of the present result with Mi-BDMA. /Polonium-210 and chelating agents/
[Rencova J et al; Int J Radiat Biol 76 (10): 1409-15 (2000)] **PEER REVIEWED** PubMed Abstract

The protective effect of N,N'-di(2-hydroxyethyl)ethylene-diamine-N,N'-biscarbodithioate (HOEtTTC) against the subacute lethal radiotoxicity of polonium-210 was investigated in a survival study and by histopathological and hematological examinations of some organs and tissues in Sprague-Dawley rats. This effect was compared with that of N,N'-diethylamine-N-carbodithioate (diethy dithiocarbamate, DDTC). In the survival study, rats injected in intravenously solely with a lethal amount of polonium-210 (1.45 MBq kg-1 body mass) died within 14-44 days while 90% of rats treated with HOEtTTC survived for 5 months until sacrificed. When treated with DDTC all rats died within 36-93 days. In the histopathological examination, relevant changes resulting from incorporation of polonium-210 were found in lymph nodes, thymus and humeral bone marrow. After the treatment with HOEtTTC no pathological changes were observed. In the hematological examination, severe reduction in blood and femoral bone marrow (BM) cell counts was revealed in rats injected with polonium-210. This reduction was reversed by treatment with HOEtTTC. Treatment with DDTC led only to partial recovery of blood and BM cell count. In conclusion, under the conditions of the experiment only HOEtTTC was fully effective in reducing subacute lethal radiotoxicity of polonium-210. /Polonium-210 and chelating agents/
[Rencova J et al; Int J Radiat Biol 72 (3): 341-8 (1997)] **PEER REVIEWED** PubMed Abstract

The time dependence of organ distribution and excretion of intravenously (iv) injected polonium-210 was investigated after the single or repeated administration of N,N'-diethylamine-N-carbodithioate (diethyldithiocarbamate, DDTC) and three bis-dithiocarbamates: N,N'-dimethylethylenediamine-N,N'-biscarbodithioate (MeTTC), N,N'-diethylethylenediamine-N,N'-biscarbodithioate (EtTTC), and N,N'-di)20hydroxyethyl)ethylenediamine-N,N'-biscarbodithioate++ + (HOEtTTC). The biokinetics of iv injected polonium-210 was used as a model for the behavior of polonium-210 absorbed into the blood from any other site of entry into the body. The most effective chelating agent was HOEtTTC, which was not only effective when injected subcutaneously (sc) immediately after polonium-210, but also 1 h later. Toxic effects of DDTC were observed in a metabolic study when the effect of HOEtTTC was compared with that of DDTC. DDTC caused accumulation of polonium-210 in brain and transiently in liver. When HOEtTTC was administered, the fecal excretion of polonium-210 was increased from the very beginning. MeTTC, EtTTC and N-(2,3-dimercaptopropyl)phtalamidic acid (DMPA) were ineffective when the treatment started 1 h after iv injection of polonium-210. /Polonium-210 and chelating agents/
[Rencova J et al; Int J Radiat Biol 67 (2): 229-34 (1995)] **PEER REVIEWED** PubMed Abstract

Nine different sulfur-based chelators, including dithiols and dithiocarbamates, were examined for their ability to remove polonium-210 from the rat. In general, treatments merely caused a redistribution of polonium-210 in the body. Greatest reduction of polonium-210 in blood was achieved by 2,3-dimercaptopropanol (BAL), sodium diethyldithiocarbamate (DDTC), and N-(2,3-dimercaptopropyl) phthalamidic acid (DMPA). Nearly all the compounds tested decreased polonium-210 in the spleen and muscle. On the other hand, BAL and DDTC substantially increased the accumulation of polonium-210 in the brain while DMPA, DMPS (sodium 2,3-dimercaptopropane-1-sulphonate) and DMSA (meso-2,3-dimercaptosuccinic acid) increased by several times the polonium-210 in kidneys. A less pronounced increase of polonium-210 was sometimes observed in liver (due to DDTC and DMPA) and in muscle (due to BAL and DDTC). Three of the dithiocarbamates (BGDTC, MeOBGDTC and BLDTC) did not increase accumulation of polonium-210 in the brain and muscle but they reduced polonium-210 in blood to a lesser degree than DDTC. A derivative of DMSA (Mi-ADMS) reduced polonium-210 in blood, bone and muscle more than DMSA, but at the same time increased Po-210 in the kidney. When BAL or DDTC were combined with other agents there was a greater reduction in the whole-body burden of polonium-210. Removal of polonium-210 from the bone, spleen and kidneys by BAL was increased by repeated treatment. However, under similar experimental conditions the effect of a single injection of BAL on polonium-210 in blood was less pronounced when the period of observation was prolonged. Total-body retention of polonium-210 could not be reduced to less than 85% of the untreated controls by any of the chelators tested. In spite of this some of them (BAL, DMPS, DMSA, DMPA) could still have a useful role in reducing the toxicity of polonium-210. /Polonium-210 and chelating agents/
[Rencova J et al; Int J Radiat Biol 63 (2): 223-32 (1993)] **PEER REVIEWED** PubMed Abstract

Syrian Golden hamsters received 8 weekly intratracheal instillations of 0.2 uCi of the alpha-emitting isotope polonium-210 while being exposed to an atmosphere of 65% oxygen in the inspired air. Three months later, 42% of the animals had poorly differentiated lung carcinomas. On the other hand, no lung tumors were found in hamsters that received intratracheal instillations of polonium-210 and were kept in air. It is concluded that diffuse cell hyperplasia in the lung, caused by an inhalant, may constitute an additional risk factor in the pathogenesis of alpha-radiation induced lung cancer. /Polonium-210 and oxygen/
[Witschi H and Schuller HM; Cancer Lett 60 (3): 193-7 (1991)] **PEER REVIEWED** PubMed Abstract

The influence of lead-210 on the effective half life of polonium-210 in various organs of the male rat was investigated. Male rats were injected with an equilibrium solution of radiumDEF. Rats were sacrificed over 140 days post injection and skull, femur, spine, kidney, gonads, spleen, liver, lungs, blood and heart removed, weighed and analyzed for their polonium-210 and lead-210 content. The data indicate that soft tissue half life and distribution values for polonium-210 will be influenced by the release of lead-210 from the bone compartment. The results bring into question the MPC values for decay chains (i.e. RaDEF decay chain) in which daughter products can be redistributed to other organs thereby increasing the radiation dose to these organs. /Polonium-210 and lead-210/
[Torvik E et al; Health Phys 26 (1): 81-7 (1974)] **PEER REVIEWED** PubMed Abstract

Leaf tobacco contains minute amounts of lead-210 and polonium-210, both of which are radioactive carcinogens and both of which can be found in smoke from burning tobacco. Tobacco smoke also contains carcinogens that are nonradioactive. People who inhale tobacco smoke are exposed to higher concentrations of radioactivity than nonsmokers. Deposits of lead-210 and alpha particle-emitting polonium form in the lungs of smokers, generating localized radiation doses far greater than the radiation exposures humans experience from natural sources. This radiation exposure, delivered to sensitive tissues for long periods of time, may induce cancer both alone and synergistically with nonradioactive carcinogens. This article explores the relationship between the radioactive and nonradioactive carcinogens in leaf tobacco and tobacco smoke and the risk of cancer in those who inhale tobacco smoke.
[Kilthau GF; Radiol Technol 67 (3): 217-22 (1996)] **PEER REVIEWED** PubMed Abstract

Pharmacology:

Interactions:
Polonium-210 is one of the most hazardous radionuclides. As recently as 1988, there have been concerns regarding accidental exposures of humans to it. Yet, there have been no studies on the effectiveness of the newer dithiol chelating agents in increasing the excretion of this radioactive heavy metal. In order to accomplish this, a safe and effective method for determining the radioactivity of polonium-210, an alpha emitter, in the feces was developed. The excretion of polonium-210 was studied by giving male Sprague-Dawley rats 210Po (3.33x10+7) cpm/kg, intraperitoneal); 1 hr later they were given either 5% sodium bicarbonate, N-(2,3-dimercaptopropyl)phthalamidic acid (DMPA) or meso-dimercaptosuccinic acid (DMSA) (0.20 mmol/kg, subcutaneous). Treatment was repeated daily for 12 days. DMPA and DMSA increased the urinary excretion of polonium-210, as compared to control animals, 8-fold and 5-fold, respectively. DMPA increased the fecal excretion of polonium-210 compared to the other treatments and also decreased the level of polonium-210 in the spleen, a radiosensitive organ. DMPA (0.20 mmol/kg, intravenous) increased biliary levels of polonium-210 5-fold compared to controls. The results indicate that DMPA has greater specificity in chelating and increasing the excretion of polonium-210 than DMSA. /Polonium-210 and chelating agents/
[Bogdan GM, Aposhian HV; Biol Met 3 (3-4): 232-6 (1990)] **PEER REVIEWED** PubMed Abstract

The same group studied intratracheal instillation of polonium-210 and benzo(a)pyrene into male Syrian golden hamsters from 11 weeks of age in order to examine the possible synergistic effects of combined exposures to these two compounds, both of which are present in tobacco smoke. Various exposure strategies were used, including simultaneous administration of the two agents and sequential administration of one agent before the other. In preliminary studies of simultaneous administration, an additive but not a synergistic lung cancer response was seen. In the study of sequential administration, 312 hamsters each received a single intratracheal instillation of 40 nCi of polonium-210 (1,480 Bq) either in saline or on Fe2O3 particles at 11 weeks of age. Eighteen weeks later, half of the animals were given a series of seven weekly intratracheal instillations of 0.3 mg benzo[a]pyrene adsorbed on 3 mg Fe2O3 carrier particles. No lung tumours occurred in 65 animals given polonium-210 alone on Fe2O3 particles and one occurred in 74 animals given polonium-210 in 0.9% saline. Addition of the seven instillations of benzo[a]-pyrene raised these numbers to 13 of 72 and 10 of 63 /with/ tumors, respectively, which the authors interpreted as a synergistic effect. Subsequent studies showed that multiple instillations of 0.9% saline alone could also significantly increase the number of polonium-210 induced lung tumors, even when no chemical carcinogen was present. The authors suggested that their results showed a minimal interaction between polonium-210 and benzo[a]- pyrene. The effect of repeated saline injections after instillations of polonium-210 was considered to mimic the effect of chronic lung irritation, such as might be produced by cigarette smoke acting as a potentiating factor. /Polonium-210 and benzo(a)pyrene/
[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. V. 78 252 (2001) Part 2] **PEER REVIEWED**

Contaminated puncture wounds were simulated in rat by intramuscular injection of polonium-210. The aim of the study was to determine the effectiveness of chelation treatment as a function of time, dosage, and route of chelate administration. Ten newly synthesized substances containing vicinal sulfhydryl and carbodithioate groups were used and their effect was compared with that of chelators clinically applicable in man, BAL (2,3-dimercaptopropane-1-ol), DMPS (2,3-dimercaptopropane-1-sulfonate), DMSA (meso-2,3-dimercaptosuccinic acid), and DDTC (sodium diethylamine-N-carbodithioate). The results indicate first that complete removal of polonium-210 from the injection site is achieved by only two local injections of DMPS, beginning as late as 2 hr after injection of polonium-210. Second, many of the substances used merely induce translocation of polonium-210 from the injection site into other tissues. Third, a combined local treatment at the injection site with DMPS plus repeated systemic, subcutaneous, treatments with HOEtTTC (N,N'-di-(2-hydroxyethyl)ethylenediamine-N,N-biscarbodithioate), a derivative of DDTC, results after 2 weeks in a reduction of the estimated total body retention of polonium-210 to about one-third of that in untreated controls. In the latter case the cumulative excretion of polonium-210 increased from 8 to 54%, mainly via the feces. /Polonium-210 and chelating agents/
[Volf V et al; Int J Radiat Biol 68 (4): 395-404 (1995)] **PEER REVIEWED** PubMed Abstract

Repeated subcutaneous chelation was conducted after intravenous injection of polonium-210 nitrate /to rats/. For reduction of polonium-210 retention the treatment with vicinal dithiols meso-and rac-2,3-dimercaptosuccinic acid (DMSA), mono-i-amylmeso-2,3-dimercapto succinate (Mi-ADMS) and mono-N-(i-butyl)-meso-2,3-dimercapto succinamide (Mi-BDMA) were used. For the reduction of toxic effects of polonium-210, treatment effectiveness of Mi-BDMA was compared with that of N,N'-di(2-hydroxyethyl)ethylenediamine-N,N'-biscarbodithioate (HOEtTTC, reference compound). ... Treatment with meso-DMSA and rac-DMSA altered the main excretion route of polonium-210, reduced its contents in the liver but increased its deposition in the kidneys. Treatment with Mi-ADMS or Mi-BDMA increased total excretion of polonium-210, mainly via the feces. Only Mi-BDMA decreased polonium-210 levels in the kidneys. The effectiveness of all chelators decreased with delay in the start of treatment. In a survival study, the lives of rats treated early with Mi-BDMA or delayed with HOEtTTC were prolonged three-fold when compared with rats receiving a lethal amount of polonium-210 only. ... Of the vicinal dithiols examined, Mi-BDMA was the best mobilizing chelating agent for polonium-210 and it reduced polonium-210 toxicity when the treatment started immediately. However, the detoxification efficacy of the immediate treatment with HOEtTTC, observed in our previous study, was superior to that of the present result with Mi-BDMA. /Polonium-210 and chelating agents/
[Rencova J et al; Int J Radiat Biol 76 (10): 1409-15 (2000)] **PEER REVIEWED** PubMed Abstract

The protective effect of N,N'-di(2-hydroxyethyl)ethylene-diamine-N,N'-biscarbodithioate (HOEtTTC) against the subacute lethal radiotoxicity of polonium-210 was investigated in a survival study and by histopathological and hematological examinations of some organs and tissues in Sprague-Dawley rats. This effect was compared with that of N,N'-diethylamine-N-carbodithioate (diethy dithiocarbamate, DDTC). In the survival study, rats injected in intravenously solely with a lethal amount of polonium-210 (1.45 MBq kg-1 body mass) died within 14-44 days while 90% of rats treated with HOEtTTC survived for 5 months until sacrificed. When treated with DDTC all rats died within 36-93 days. In the histopathological examination, relevant changes resulting from incorporation of polonium-210 were found in lymph nodes, thymus and humeral bone marrow. After the treatment with HOEtTTC no pathological changes were observed. In the hematological examination, severe reduction in blood and femoral bone marrow (BM) cell counts was revealed in rats injected with polonium-210. This reduction was reversed by treatment with HOEtTTC. Treatment with DDTC led only to partial recovery of blood and BM cell count. In conclusion, under the conditions of the experiment only HOEtTTC was fully effective in reducing subacute lethal radiotoxicity of polonium-210. /Polonium-210 and chelating agents/
[Rencova J et al; Int J Radiat Biol 72 (3): 341-8 (1997)] **PEER REVIEWED** PubMed Abstract

The time dependence of organ distribution and excretion of intravenously (iv) injected polonium-210 was investigated after the single or repeated administration of N,N'-diethylamine-N-carbodithioate (diethyldithiocarbamate, DDTC) and three bis-dithiocarbamates: N,N'-dimethylethylenediamine-N,N'-biscarbodithioate (MeTTC), N,N'-diethylethylenediamine-N,N'-biscarbodithioate (EtTTC), and N,N'-di)20hydroxyethyl)ethylenediamine-N,N'-biscarbodithioate++ + (HOEtTTC). The biokinetics of iv injected polonium-210 was used as a model for the behavior of polonium-210 absorbed into the blood from any other site of entry into the body. The most effective chelating agent was HOEtTTC, which was not only effective when injected subcutaneously (sc) immediately after polonium-210, but also 1 h later. Toxic effects of DDTC were observed in a metabolic study when the effect of HOEtTTC was compared with that of DDTC. DDTC caused accumulation of polonium-210 in brain and transiently in liver. When HOEtTTC was administered, the fecal excretion of polonium-210 was increased from the very beginning. MeTTC, EtTTC and N-(2,3-dimercaptopropyl)phtalamidic acid (DMPA) were ineffective when the treatment started 1 h after iv injection of polonium-210. /Polonium-210 and chelating agents/
[Rencova J et al; Int J Radiat Biol 67 (2): 229-34 (1995)] **PEER REVIEWED** PubMed Abstract

Nine different sulfur-based chelators, including dithiols and dithiocarbamates, were examined for their ability to remove polonium-210 from the rat. In general, treatments merely caused a redistribution of polonium-210 in the body. Greatest reduction of polonium-210 in blood was achieved by 2,3-dimercaptopropanol (BAL), sodium diethyldithiocarbamate (DDTC), and N-(2,3-dimercaptopropyl) phthalamidic acid (DMPA). Nearly all the compounds tested decreased polonium-210 in the spleen and muscle. On the other hand, BAL and DDTC substantially increased the accumulation of polonium-210 in the brain while DMPA, DMPS (sodium 2,3-dimercaptopropane-1-sulphonate) and DMSA (meso-2,3-dimercaptosuccinic acid) increased by several times the polonium-210 in kidneys. A less pronounced increase of polonium-210 was sometimes observed in liver (due to DDTC and DMPA) and in muscle (due to BAL and DDTC). Three of the dithiocarbamates (BGDTC, MeOBGDTC and BLDTC) did not increase accumulation of polonium-210 in the brain and muscle but they reduced polonium-210 in blood to a lesser degree than DDTC. A derivative of DMSA (Mi-ADMS) reduced polonium-210 in blood, bone and muscle more than DMSA, but at the same time increased Po-210 in the kidney. When BAL or DDTC were combined with other agents there was a greater reduction in the whole-body burden of polonium-210. Removal of polonium-210 from the bone, spleen and kidneys by BAL was increased by repeated treatment. However, under similar experimental conditions the effect of a single injection of BAL on polonium-210 in blood was less pronounced when the period of observation was prolonged. Total-body retention of polonium-210 could not be reduced to less than 85% of the untreated controls by any of the chelators tested. In spite of this some of them (BAL, DMPS, DMSA, DMPA) could still have a useful role in reducing the toxicity of polonium-210. /Polonium-210 and chelating agents/
[Rencova J et al; Int J Radiat Biol 63 (2): 223-32 (1993)] **PEER REVIEWED** PubMed Abstract

Syrian Golden hamsters received 8 weekly intratracheal instillations of 0.2 uCi of the alpha-emitting isotope polonium-210 while being exposed to an atmosphere of 65% oxygen in the inspired air. Three months later, 42% of the animals had poorly differentiated lung carcinomas. On the other hand, no lung tumors were found in hamsters that received intratracheal instillations of polonium-210 and were kept in air. It is concluded that diffuse cell hyperplasia in the lung, caused by an inhalant, may constitute an additional risk factor in the pathogenesis of alpha-radiation induced lung cancer. /Polonium-210 and oxygen/
[Witschi H and Schuller HM; Cancer Lett 60 (3): 193-7 (1991)] **PEER REVIEWED** PubMed Abstract

The influence of lead-210 on the effective half life of polonium-210 in various organs of the male rat was investigated. Male rats were injected with an equilibrium solution of radiumDEF. Rats were sacrificed over 140 days post injection and skull, femur, spine, kidney, gonads, spleen, liver, lungs, blood and heart removed, weighed and analyzed for their polonium-210 and lead-210 content. The data indicate that soft tissue half life and distribution values for polonium-210 will be influenced by the release of lead-210 from the bone compartment. The results bring into question the MPC values for decay chains (i.e. RaDEF decay chain) in which daughter products can be redistributed to other organs thereby increasing the radiation dose to these organs. /Polonium-210 and lead-210/
[Torvik E et al; Health Phys 26 (1): 81-7 (1974)] **PEER REVIEWED** PubMed Abstract

Leaf tobacco contains minute amounts of lead-210 and polonium-210, both of which are radioactive carcinogens and both of which can be found in smoke from burning tobacco. Tobacco smoke also contains carcinogens that are nonradioactive. People who inhale tobacco smoke are exposed to higher concentrations of radioactivity than nonsmokers. Deposits of lead-210 and alpha particle-emitting polonium form in the lungs of smokers, generating localized radiation doses far greater than the radiation exposures humans experience from natural sources. This radiation exposure, delivered to sensitive tissues for long periods of time, may induce cancer both alone and synergistically with nonradioactive carcinogens. This article explores the relationship between the radioactive and nonradioactive carcinogens in leaf tobacco and tobacco smoke and the risk of cancer in those who inhale tobacco smoke.
[Kilthau GF; Radiol Technol 67 (3): 217-22 (1996)] **PEER REVIEWED** PubMed Abstract

Environmental Fate & Exposure:

Environmental Fate/Exposure Summary:
Polonium is a naturally occurring radioactive element that occurs in very low concentrations in the earth's crust, approximately one part in 1X10+15. Polonium-210 is a decay product of the ubiquitous naturally occurring uranium-238 isotope and is widely distributed in the earth's crust in small amounts; uranium ores contain about 100 micrograms of polonium-210 per ton of uranium ore. Polonium-210 is a decay product radon-222, a naturally occurring radioactive gas (half-life = 3.8 days). Polonium-210 will be released to air through decay process of radon-222, and will be deposited to the earth's surface by rain or snow. More than 25 isotopes of polonium are known and all are radioactive. Polonium-210 is usually produced artificially by the bombardment of the stable bismuth-209 isotope with neutrons in a nuclear reactor, forming radioactive bismuth-210, which decays to polonium-210. Polonium-208 and polonium-209 are also produced in reactors or particle accelerators, but are very expensive to produce. Polonium-210 is used mainly in static eliminators in a sealed source. Polonium-210 is release to the atmosphere and water by various industries, such as elementary phosphorus production, phosphoric acid production, iron and steel production, coal tar treatment, coal-fired power plants, cokes production, cement industry, ceramics, mineral sands handling, and oil and gas extraction. The largest releases to air and water were reported for elementary phosphorus and phosphoric acid industries, respectively. Polonium forms ionic compounds in its II and IV oxidation

states. The IV oxidation state is the common valence for polonium. Polonium only occasionally occurs in its II and rarely in its VI oxidation states. If release to air, ionic polonium compounds would not be volatile and would exist solely in the particulate phase in the ambient atmosphere. Particulate-phase polonium compounds will be removed from the atmosphere by wet or dry deposition. In studies of various radionuclides in the Tagus estuary (Portugal) polonium-210 was found to be sorbed rapidly to settling particles. Bottom sediments in the estuary represent a sink for polonium-210 both from natural sources and industrial waste releases. Based on this study, it would be likely that polonium compounds would be tightly bound to soils and would not be expected to be mobile. Rapid sorption of polonium-210 to sediments in the Tagus estuary reduced the bioavailability of polonium-210 to estuarine organisms; no enhancement of polonium-210 levels were detected in biota in the Tagus estuary. Enhanced bioaccumulation of polonium-210 has been observed near the point of low pH phosphate waste releases. Uptake by biota may occur before neutralization of the highly acidic wastes. Polonium-210 and plutonium-(239+240) were found to accumulate strongly in some species of Baltic biota; mean BCF values ranged from 900 to 37,000. Ionic polonium compounds would not volatilize from moist or dry soil surfaces or from water surfaces. Since trace amounts of polonium-210 are found in all environmental media, the general population is exposed to small amounts of polonium. The average amount of polonium-210 in the human body is approximately 1X10-9 curie. Individuals who smoke may be exposed to increased polonium concentrations; studies have shown that twice as much polonium is found in the ribs of smokers as compared to nonsmokers. In studies of the lichen-caribou-human food chain near uranium mining operations in northern Saskatchewan, Canada, polonium-210 was found in soft tissues of caribou. Consumption of these tissues enhances the transfer of polonium-210 through the lichen-caribou-human food chain. Occupational exposure to polonium compounds may also occur to individuals involved in scientific research using polonium or in the manufacture of products containing polonium. (SRC)
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Probable Routes of Human Exposure:
Since trace amounts of polonium-210 are found in all environmental media(1), the general population is exposed to small amounts of polonium(SRC). The average amount of polonium-210 in the human body is approximately 1X10-9 curie(1) Individuals who smoke may be exposed to increased polonium(SRC); studies have shown that twice as much polonium is found in the ribs of smokers as compared to nonsmokers(1,2). In studies of the lichen-caribou-human food chain near uranium mining operations in northern Saskatchewan, Canada, polonium-210 was found in soft tissues of caribou(3). Consumption of these tissues enhances the transfer of polonium-210 through the lichen-caribou-human food chain(3). Occupational exposure to polonium compounds may also occur to individuals involved in scientific research using polonium or in the manufacture of products containing polonium(SRC).
[(1) Argonne National Laboratory/EVS. Human Health Fact Sheet, August 2005. Polonium. Available at: http://www.ead.anl.gov/pub/doc/polonium.pdf as of Jan 24, 2006. (2) Eisenbud M, Gesell T, eds; Environmental radioactivity. 4th ed. San Diego: Academic Press. pp. 134-200 (1997) (3) Thomas PA, Gates TE; Environ Health Perspect 107: 527-37 (1999)] **PEER REVIEWED**

Body Burden:
The average amount of polonium-210 in the human body is approximately 1X10-9 curie(1). Polonium-210 concentration in various human tissues from Europe, Japan, and the US ranged from 190-370, 410-970, 420-1,200, 40-310, and 2,200-2,900 mBq/kg in lung, liver, kidney, muscle and other tissues, and bone, respectively(2). Polonium-210 concentration in various human tissues from the US were 190, 410-540, 420, 130-220, and 2,900 mBq/kg in lung, liver, kidney, muscle and other tissues, and bone, respectively(2).
[(1) Argonne National Laboratory/EVS. Human Health Fact Sheet, August 2005. Polonium. Available at: http://www.ead.anl.gov/pub/doc/Polonium.pdf as of Jan 24, 2006. (2) UNSCEAR. 2000. Sources and effects of ionizing radiation. UNSCEAR 2000 report. Volume 1. United Nations Scientific Committee on the Effects of Atomic Radiation. Annex B: Exposures from natural radiation sources. Available at: http://www.unscear.org as of Jan 25, 2006.] **PEER REVIEWED**

Average Daily Intake:
Annual intakes of polonium-210 in the diet ranging from 18 to 220 Bq have been reported in Argentina and Japan, respectively(1). An annual polonium-210 intake of 22 Bq was reported in the US(1).
[(1) UNSCEAR. 2000. Sources and effects of ionizing radiation. UNSCEAR 2000 report. Volume 1. United Nations Scientific Committee on the Effects of Atomic Radiation. Available at: http://www.unscear.org as of Jan 25, 2006.] **PEER REVIEWED**

Natural Pollution Sources:
Polonium is a naturally occurring radioactive element that occurs in very low concentrations in the earth's crust, approximately one part in 1X10+15(1). Polonium-210 is a decay product of the ubiquitous naturally occurring uranium-238 isotope and is widely distributed in the earth's crust in small amounts(1); uranium ores contain about 100 micrograms of polonium-210 per ton of uranium ore(3). Polonium-210 is a decay product radon-222, a naturally occurring radioactive gas (half-life = 3.8 days)(2). Polonium-210 will be released to air through decay process of radon-222(2), and will be deposited to the earth's surface by rain or snow(SRC).
[(1) Argonne National Laboratory/EVS. Human Health Fact Sheet, August 2005. Polonium. Available at: http://www.ead.anl.gov/pub/doc/Polonium.pdf as of Jan 24, 2006. (2) Eisenbud M, Gesell T, eds; Environmental radioactivity. 4th ed. San Diego: Academic Press. pp. 134-200 (1997) (3) Lide DR, ed; CRC Handbook of Chemistry and Physics. 86th ed. Boca Raton, FL: CRC Press Inc., 2005-2006. p. 4-27 to 4-28 (2005)] **PEER REVIEWED**

Artificial Pollution Sources:
Polonium-210 is usually produced artificially by the bombardment of the stable bismuth-209 isotope with neutrons in a nuclear reactor(1). This forms radioactive bismuth-210, which decays to polonium-210(1). Polonium-208 and -209 are also produced in reactors or particle accelerators, but are very expensive to produce(1). Polonium-210 is used mainly in static eliminators in a sealed source(1). Polonium-210 is released to the atmosphere during the calcining of phosphate rock during the production of elemental phosphorus(2). Polonium-210 is released to the atmosphere and water by various industries, such as elementary phosphorus production, phosphoric acid production, iron and steel production, coal tar treatment, coal-fired power plants, cokes production, cement industry, ceramics, mineral sands handling, and oil and gas extraction(3). The largest releases to air and water were reported for elementary phosphorus and phosphoric acid industries, respectively(3).
[(1) Argonne National Laboratory/EVS. Human Health Fact Sheet, August 2005. Polonium. Available at: http://www.ead.anl.gov/pub/doc/Polonium.pdf as of Jan 24, 2006. (2) Eisenbud M, Gesell T, eds; Environmental radioactivity. 4th ed. San Diego: Academic Press. pp. 134-200 (1997) (3) UNSCEAR. 2000. Sources and effects of ionizing radiation. UNSCEAR 2000 report. Volume 1. United Nations Scientific Committee on the Effects of Atomic Radiation. Annex B: Exposures from natural radiation sources. Available at: http://www.unscear.org as of Jan 25, 2006.] **PEER REVIEWED**

Environmental Fate:
TERRESTRIAL FATE: In studies of various radionuclides in the Tagus estuary (Portugal) polonium-210 was found to be rapidly sorbed to settling particles and that bottom sediments in the estuary represent a sink for polonium-210 both from natural sources and industrial waste releases(1). Based on this study, it would be likely that polonium compounds would be tightly bound to soils and would not be expected to be mobile(SRC). Ionic polonium compounds would not volatilize from moist or dry soil surfaces(SRC).
[(1) Carvalho FP; Sci Total Environ 196: 151-61 (1997) (2) Skwarzec B; Czech J Phys 49: 461-6 (1999)] **PEER REVIEWED**

AQUATIC FATE: In studies of various radionuclides in the Tagus estuary (Portugal) polonium-210 was found to be rapidly sorbed to settling particles(1). Bottom sediments in the estuary represent a sink for polonium-210 both from natural sources and industrial waste releases(1). Rapid sorption of polonium-210 to sediments in the Tagus estuary reduced the bioavailability of polonium-210 to estuarine organisms; no enhancement of polonium-210 levels were detected in biota in the Tagus estuary(1). Enhanced bioaccumulation of polonium-210 has been observed near the point of low pH phosphate waste releases(1). Uptake by biota may occur before neutralization of the highly acidic wastes(1). Polonium-210 and plutonium-(239+240) were found to strongly accumulate in some species of Baltic biota; mean BCF values ranged from 900 to 37,000(2).
[(1) Carvalho FP; Sci Total Environ 196: 151-61 (1997) (2) Skwarzec B; Czech J Phys 49: 461-6 (1999)] **PEER REVIEWED**

ATMOSPHERIC FATE: Ionic polonium compounds would not be volatile and would exist solely in the particulate phase in the ambient atmosphere(SRC). Particulate-phase polonium compounds will be removed from the atmosphere by wet or dry deposition(SRC). Polonium-210 is released to air through decay process of radon-222(1), and will be deposited to the earth's surface by rain or snow(SRC).
[(1) Eisenbud M, Gesell T, eds; Environmental radioactivity. 4th ed. San Diego: Academic Press. pp. 134-200 (1997)] **PEER REVIEWED**

Environmental Abiotic Degradation:
Polonium forms ionic compounds in its II and IV oxidation states(1). The IV oxidation state is the common valence for polonium(2). Polonium only occasionally occurs in its II and rarely in its VI oxidation states(2).
[(1) Cotton FA et al; Advanced Inorganic Chemistry 6th ed. NY, NY: John Wiley and Sons, p. 1147 (1999) (2) O'Neil MJ, ed; The Merck Index. 13th ed. Whitehouse Station, NJ: Merck and Co., Inc., p. 1357 (2001)] **PEER REVIEWED**

Environmental Bioconcentration:
Polonium-210 and plutonium-(239+240) were found to accumulate strongly in some species of Baltic biota; mean BCF values ranged from 900 to 37,000(1). Rapid

sorption of polonium-210 to sediments in the Tagus estuary (Portugal) reduced the bioavailability of polonium-210 to estuarine organisms; no enhancement of polonium-210 levels were detected in biota in the Tagus estuary(2). Enhanced bioaccumulation of polonium-210 has been observed near the point of low pH phosphate waste releases(2). Uptake by biota may occur before neutralization of the highly acidic wastes(2).
[(1) Skwarzec B; Czech J Phys 49: 461-6 (1999) (2) Carvalho FP; Sci Total Environ 196: 151-61 (1997)] **PEER REVIEWED**

Soil Adsorption/Mobility:
In studies of various radionuclides in the Tagus estuary (Portugal) polonium-210 was found to be rapidly sorbed to settling particles(1). Bottom sediments in the estuary represent a sink for polonium-210 both from natural sources and industrial waste releases(1).
[(1) Carvalho FP; Sci Total Environ 196: 151-61 (1997)] **PEER REVIEWED**

Volatilization from Water/Soil:
Polonium compounds are ionic and would not volatilize from moist or dry soil surfaces or from water surfaces. (SRC)
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Environmental Water Concentrations:
DRINKING WATER: Concentrations of polonium-210 in drinking water ranging from 0.2-7600, 0.1-200, 0.5, and 7-44 mBq/kg have been reported in samples from Finland, Germany, Poland, and Romania, respectively(1). A mean polonium-210 concentration of 0.1 pCi/L was reported samples collected in 1998-1999 from 27 US states and 8 physicographic provinces as part of a US Geological Survey study of groundwater that is used for drinking water(2).
[(1) UNSCEAR. 2000. Sources and effects of ionizing radiation. UNSCEAR 2000 report. Volume 1. United Nations Scientific Committee on the Effects of Atomic Radiation. Annex B: Exposures from natural radiation sources. Available at: http://www.unscear.org as of Jan 25, 2006. (2) Michael J et al; Occurrence of Selected Radionuclides in Ground Water Used for Drinking Water in the United States: A Targeted Reconnaissance Survey, 1998. U.S. Geological Survey Water-Resources Investigations Report 00-4273, 2001. Available at: http://pubs.usgs.gov/wri/wri004273/ as of Feb 14, 2006.] **PEER REVIEWED**

SURFACE WATER: Polonium-210 concentrations in suspended matter in the Tagus estuary (Portugal) ranged from 56 to 140 Bq/kg dry weight(1). Polonium-210 concentrations in filtered (at 0.45 micrometer) seawater samples from the baie de Seine (Channel coast of France), a site of industrial releases of phosphatic gypsum waste, ranged from 0.2 to 1.6 mBq/L(2). Polonium-210 concentrations in unfiltered seawater samples ranged form 0.7 to 16 mBq/L(2). Polonium-210 concentrations in suspended matter samples ranged from 27 to 179 Bq/kg dry weight(2).
[(1) Carvalho FP; Sci Total Environ 159: 201-14 (1995) (2) Germain P et al; Sci Total Environ 164: 109-23 (1995)] **PEER REVIEWED**

Sediment/Soil Concentrations:
SEDIMENT: The Seine estuary (France) is the site of industrial releases of phosphatic gypsum waste(1). Polonium-210 concentrations sediments collected from the bed of the Seine ranged from 75 to 285 Bq/kg dry weight(1). The highest concentrations, 949 and 1,058 Bq/kg dry weight, were found in the estuary within 0.1 km of the outlet pipe(1).
[(1) Germain P et al; Sci Total Environ 164: 109-23 (1995)] **PEER REVIEWED**

Atmospheric Concentrations:
URBAN/SUBURBAN: Concentrations of polonium-210 in air ranging from 10-40 and 12-80 uBq/cu m have been reported in the US and Germany, respectively(1).
[(1) UNSCEAR. 2000. Sources and effects of ionizing radiation. UNSCEAR 2000 report. Volume 1. United Nations Scientific Committee on the Effects of Atomic Radiation. Annex B: Exposures from natural radiation sources. Available at: http://www.unscear.org as of Jan 25, 2006.] **PEER REVIEWED**

Food Survey Values:
The following polonium-210 concentrations (mBq/kg) in foods from North America, Europe, and Asia have been reported: 2-220 (milk products); 37-67,000 (meat products); 15-1,900 (grain products); 4-7,400 (leafy vegetables); 12-5,200 (root vegetables and fruits); and 50-120,000 (fish products)(1). Mean polonium-210 concentrations (Bq/kg, wet weight) were reported in the following food groups as part of a Chinese total diet study 1990: cereals, 0.09 (range 0.00-0.31); legumes and nuts, 0.10 (0.00-0.11); potatoes, 0.03 (0.00-0.11); meats, 0.13 (0.05-0.26); eggs, 0.32 (0.00-0.67); aquatic foods, 3.76 (0.40-33.87); milk, 0.02 (0.00-0.04); vegetables, 0.46 (0.06-0.91); fruits, 0.03 (0.00-0.09); sugar, 0.003 (0.00-0.01); beverages and water, 0.004 (0.00-0.02); alcoholic beverages, 0.003 (0.00-0.01)(2). In a study of Dutch fishery products, polonium-210 concentrations were 1-2 Bq/kg in fish and 25-30 Bq/kg in mussels and shrimp(3).
[(1) UNSCEAR. 2000. Sources and effects of ionizing radiation. UNSCEAR 2000 report. Volume 1. United Nations Scientific Committee on the Effects of Atomic Radiation. Annex B: Exposures from natural radiation sources. Available at: http://www.unscear.org as of Jan 25, 2006. (2) Chen J, Gao J; J AOAC Intl 76: 1193-205 (1993) (3) Hagel P; Environ Monit Assess 7: 257-62 (1986)] **PEER REVIEWED**

Plant Concentrations:
Mean concentrations in two lichens species, Cladina stellaris and C. mitis, collected near uranium mining operations in northern Saskatchewan, Canada were 329 and 253 Bq/kg dry weight, respectively(1). Polonium-210 concentrations in Fucus vesiculosus (L.) (brown seaweed) from the baie de Seine (Channel coast of France), a site of industrial releases of phosphatic gypsum waste, ranged from 3 to 22 Bq/kg dry weight(2)
[(1) Thomas PA, Gates TE; Environ Health Perspect 107: 527-37 (1999) (2) Germain P et al; Sci Total Environ 164: 109-23 (1995)] **PEER REVIEWED**

Fish/Seafood Concentrations:
Polonium-210 concentrations in Mytilus edulis (L.) (mussel) from the baie de Seine (Channel coast of France), a site of industrial releases of phosphatic gypsum waste, ranged from 90 to 700 Bq/kg dry weight(1).
[(1) Germain P et al; Sci Total Environ 164: 109-23 (1995)] **PEER REVIEWED**

Animal Concentrations:
Mean concentrations in tissues of caribou collected near uranium mining operations in northern Saskatchewan, Canada were 367 (bone), 286 (liver), 159 (kidney), 12.4 (muscle), 128 (rumen contents); 368 (feces), 23 (blood), 58 (fur), 30 (spleen), 36 (rumen wall), 42 (duodenum) 12.2 (colon), 31 (lung), and 79 (pancreas) Bq/kg wet weight(1). Various radionuclides were measured in bone and teeth of reindeer in the western Russian Arctic that had lived before, during, and after nuclear testing on the Archipelago Novaya Zemlya(2). Polonium-210 concentrations in reindeer bone ranged from 0.20 to 1.45 and 0.20 to 0.84 Bq/g dry weight in bone samples from reindeer that had lived during nuclear testing and after nuclear testing, respectively(2). The polonium-210 concentration in a composite of enamel and dentin from reindeer that died in 1890 as 0.025 Bq/g dry weight(2). Polonium-210 concentrations of 0.20 to 0.36 Bq/g dry weight in bone, and 0.08 Bq/g dry weight in composite enamel samples of mainland reindeer (killed in 1994) were also reported(2).
[(1) Thomas PA, Gates TE; Environ Health Perspect 107: 527-37 (1999) (2) Klevezal GA, et al; Chemosphere 42: 61-7 (2001)] **PEER REVIEWED**

Milk Concentrations:
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. ... Comparisons of model predictions show maximum overall transfer to milk following maternal ingestion during lactation of about 10% of ingested activity for ... polonium-210. ... The corresponding infant doses from milk consumption are estimated in preliminary calculations to be about 20% for polonium-210.
[Harrison JD et al; Radiat Prot Dosimetry 105 (1-4): 251-6 (2003)] **PEER REVIEWED**

Environmental Standards & Regulations:

Chemical/Physical Properties:

Color/Form:
Two allotropic forms coexist between 18 and 54 deg C /Polonium metal/
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 4-27] **PEER REVIEWED**

Boiling Point:
962 deg C /Elemental/
[O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. 13th Edition, Whitehouse Station, NJ: Merck and Co., Inc., 2001., p. 1357] **PEER REVIEWED**

Melting Point:
254 deg C /Elemental/
[O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. 13th Edition, Whitehouse Station, NJ: Merck and Co., Inc., 2001., p. 1357] **PEER REVIEWED**

Density/Specific Gravity:
9.196 g/cu cm (alpha form); 9.398 g/cu cm (beta form) /Elemental/
[O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. 13th Edition, Whitehouse Station, NJ: Merck and Co., Inc., 2001., p. 1357] **PEER REVIEWED**

Heat of Vaporization:
24.597 kcal/mole /Elemental/
[O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. 13th Edition, Whitehouse Station, NJ: Merck and Co., Inc., 2001., p. 1357] **PEER REVIEWED**

Solubilities:
Dissolved in dilute acids; slightly soluble in alkalis /Elemental/
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 4-27] **PEER REVIEWED**

Other Chemical/Physical Properties:
There are 38 isotopes and isomers of polonium(1) with atomic masses ranging from 188 to 220(2) and all are radioactive(1). Polonium is a very rare natural element(1); polonium-210, -211, -212, -214, -215, -216, and -218 are members of naturally radioactive decay chains(2).
[(1) Lide, D.R. CRC Handbook of Chemistry and Physics. 86th Ed, 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL p 4-28 (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**

Atomic number: 84; valence: 4, occasionally 2, rarely 6; isotopes range in mass number from 193-218; all are radioactive; 210 is naturally occurring; resistivity: 42 microohm-cm at 0 deg C (alpha form), 44 microohm-cm at 0 deg C (beta form)
[O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. 13th Edition, Whitehouse Station, NJ: Merck and Co., Inc., 2001., p. 1357] **PEER REVIEWED**

Low-melting, fairly volatile metal; 50% is vaporized in air in 45 hours at 55 deg C /Polonium-210/
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 4-27] **PEER REVIEWED**

Polonium-208: Atomic weight = 207.981231; half-life = 2.898 years; alpha decay; 5.213 MeV
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Polonium-209: Atomic weight = 208.982415; half-life = 102 years; alpha decay; 4.976 MeV
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Polonium-210: Atomic weight = 209.982857; half-life = 138.4 days; alpha decay; 5.407 MeV
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Polonium-211: Atomic weight = 210.986637; half-life = 0.516 seconds; alpha decay; 7.594 MeV
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Polonium-212: Atomic weight = 211.988852; half-life = 0.298 microseconds; alpha decay; 8.953 MeV
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Polonium-214: Atomic weight = 213.995186; half-life = 163.7 microseconds; alpha decay; 7.833 MeV
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Polonium-215: Atomic weight = 214.999415; half-life = 1.780 milliseconds; alpha decay; 7.526 MeV
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Polonium-216: Atomic weight = 216.001905; half-life = 0.145 seconds; alpha decay; 6.906 MeV
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Polonium-218: Atomic weight = 216.008965; half-life = 3.04 minutes; alpha decay; 6.114 MeV
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

DECAY PATHWAY: Polonium-208, half-life 2.898 years, decays via alpha emission, 5.215 MeV, to lead-204, half-life 1.4X10-17 years; decays via electron capture, 1.401 MeV, to bismuth-208, half-life 368,000 years.
[Korea Atomic Energy Research Institute. Nuclear Data Evaluation Lab. 2000. Nuclide Table. Available from, as of Feb 23, 2006: http://atom.kaeri.re.kr/ton/ **PEER REVIEWED**

DECAY PATHWAY: Polonium-209, half-life 102 years, decays via alpha emission (99.52%), 4.979 MeV, to lead-205, half-life 15,300,000 years; decays via electron capture (0.48%), 1.893 MeV, to bismuth-209, half-life stable.
[Korea Atomic Energy Research Institute. Nuclear Data Evaluation Lab. 2000. Nuclide Table. Available from, as of Feb 23, 2006: http://atom.kaeri.re.kr/ton/ **PEER REVIEWED**

DECAY PATHWAY: Polonium-210, half-life 138.376 days, decays via alpha emission,5.407 MeV, to lead-206, half-life stable.
[Korea Atomic Energy Research Institute. Nuclear Data Evaluation Lab. 2000. Nuclide Table. Available from, as of Feb 23, 2006: http://atom.kaeri.re.kr/ton/ **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:
In October 1957, the first substantially publicized release of radioactive material from a nuclear reactor accident occurred at the Windscale nuclear weapons plant at Sellafield in the United Kingdom. During a routine release of stored energy from the graphite core of a carbon dioxide-cooled, graphite-moderated reactor, operator error allowed the fuel to overheat. This led to uranium oxidation and a subsequent graphite fire. Attempts to extinguish the fire with carbon dioxide were ineffective. In the end, water was applied directly to the fuel channels but not before the fire had burned for 3 days, resulting in the release of iodine-131 (740 TBq; 20 kCi), cesium-137 (22 TBq; 0.6 kCi), polonium-210 (8.8 TBq; 0.2 kCi), ruuthenium-106 (3 TBq; 0.08 kCi), and xenon-133 (1.2 PBq; 32.4 kCi). ...The highest individual doses (approximately 100 mGy) were to the thyroids of children living near the accident site. The collective dose equivalent received in the United Kingdom and the rest of Europe was estimated to be 2,000 man.Sv, of which 900 man.Sv was from inhalation, 800 man.Sv was from ingestion, and 300 man.Sv was from external exposure. The main radionuclides contributing to the exposures were iodine-131 (37%), polonium-210 (37%), and cesium-137 (15%).

/210Po/
[DHHS/ATSDR; Toxicological Profile for Ionizing Radiation p.209 (PB/99/163388) (1999)] **PEER REVIEWED**

Uranium is widely distributed in nature and often occurs in association with other metals, usually in very low concentrations. Thus many underground mines, tunnels, or caves, have measurable amounts of the radioactive gas radon-222, a member of the uranium family which diffuses through rock and concentrates in underground openings. The primary sources of radiation exposure to persons entering such underground areas are the short-lived daughters of radon: polonium-218, lead-214, bismuth-214 and polonium-214. These elements diffuse rapidly and attach to the first surface encountered. Either the free atoms or the particulates to which they are attached are inspired and largely retained in the respiratory tract. The effects of exposure of miners to radon daughters have been observed for many centuries, although it is only in the last 40 yr that the relationship between exposure to radon daughters and an increased incidence of lung cancer has been suspected, and only in the last 5 yr that a cause-effect relationship has been clearly demonstrated. The documented instances have occurred in the Schneeburg mining district in Germany, the Joachimsthal district of Czechoslovakia, in fluorspar mines in Newfoundland, in American uranium mines, and probably in a group of American metal miners. In all instances, the medical and environmental data are not as complete or detailed as could be desired.
[Holaday, DA; Health Phys 15 (5): 547-52 (1969)] **PEER REVIEWED**

Protective Equipment & Clothing:
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**

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. ... Various materials can be used for shielding, depending on the type of radiation, its energy and intensity, and the attenuation required. ... For moderating fast neutrons a material with a high hydrogen content, such as water or polyethylene, must be included in the design. When thermal neutrons are captured in hydrogen, cadmium or other elements, high-energy gamma rays are emitted and must be considered in the shield design. Concrete is suitable for shielding both photons and neutrons and is a cost-effective material of choice when space is available. Earth is also an effective and inexpensive material that is widely used as shielding in various types of facilities. In addition to meeting radiation protection goals, the selection of shielding material is dependent upon engineering factors such as weight, cost, structural stability and compatibility.
[National Council on Radiation Protection and Measurements.. NCRP Report No. 127, Operational Radiation Safety Program p. 30-1, (1998)] **PEER REVIEWED**

/SRP/ Protective equipment and respirators do not provide protection against penetrating beta and gamma radiation. However, respirators prevent the inhalation of radioactive materials. Respirators should be tested and certified for the given use by NIOSH and persons using the respirator should have been fit tested before donning the equipment.
PEER REVIEWED

Preventive Measures:
Basic guidelines ... essential for the health and safety of radiation workers in biological labs /should include/: 1. Mouth pipetting should never be allowed ... 2. Eating and drinking, or storage of food containers in radioisotope lab should not be allowed. ... 3. Untrained individuals should not work with radioisotopes unless under direct supervision & in physical presence of an experienced individual. 4. Aid should be available when large quantities of radioisotopes are being used. ... 6. Where volatiles are in use, work should be done in a hood. ... 9. Radiation and/or contamination surveys should be conducted as appropriate ... 10. Survey instruments should be used to check hands and clothes for contamination at end of work (if radiation is suitable for detection.
[Fuscaldo, A., B. J. Erlick, and B. Hindman. (eds.). Laboratory Safety-Theory and Practice. New York: Academic Press, 1980., p. 94] **PEER REVIEWED**

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 of 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**

/For protection of the public/ Radiation fields emanating from the facility are controlled by appropriate shielding of components or equipment that are sources of radiation. The choices of control measures are highly dependent on the nature of the facility and its processes, the quantities and types of radionuclides employed or processed, and the levels and types of radiation produced. The facility management must ensure that techniques used for control of releases of radioactive materials are adequate and that they are functioning at a satisfactory level.
[National Council on Radiation Protection and Measurements. NCRP Report No. 127, Operational Radiation Safety Program p. 82, (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**

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:
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**

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:
Half-life = 2.898 years /Polonium-208/
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Half-life = 102 years /Polonium-209/
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Half-life = 138.4 days /Polonium-210/
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 11-161] **PEER REVIEWED**

Half-life of 218-Polonium is 3.1 minutes. Radiation energies: alpha 6.00 MeV. /from table/
[DHHS/ATSDR; Toxicological Profile for Ionizing Radiation p.240 (PB/99/163388) (1999)] **PEER REVIEWED**

Half-life of 214-Polonium is 164 useconds. Radiation energies: alpha 7.60 MeV; gamma 0.8 MeV. /from table/
[DHHS/ATSDR; Toxicological Profile for Ionizing Radiation p.240 (PB/99/163388) (1999)] **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 POLONIUM-203

CLASS	ORAL Ingestion ALI (uCi)	INHALATION ALI uCi)	INHALATION DAC (uCi/mL)
D, all compounds except those given for W	3E+4	6E+4	3E-5
W, oxides, hydroxides and nitrates	-	9E+4	4E-5

[NRC; Table 1, Appendix B to Part 20--Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage. Available from, as of October 15, 2006: http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Polonium-203.html **PEER REVIEWED**

OCCUPATIONAL VALUES FOR POLONIUM-205

CLASS	ORAL Ingestion ALI (uCi)	INHALATION ALI uCi)	INHALATION DAC (uCi/mL)
D, all compounds except those given for W	2E+4	4E+4	2E-5
W, oxides, hydroxides and nitrates	-	7E+4	3E-5

[NRC; Table 1, Appendix B to Part 20--Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage. Available from, as of October 15, 2006: http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Polonium-205.html **PEER REVIEWED**

OCCUPATIONAL VALUES FOR POLONIUM-207

CLASS	ORAL Ingestion ALI (uCi)	INHALATION ALI uCi)	INHALATION DAC (uCi/mL)
D, all compounds except those given for W	8E+3	3E+4	1E-5
W, oxides, hydroxides and nitrates	-	3E+4	1E-5

[NRC; Table 1, Appendix B to Part 20--Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage. Available from, as of October 15, 2006: http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Polonium-207.html **PEER REVIEWED**

OCCUPATIONAL VALUES FOR POLONIUM-210

CLASS	ORAL Ingestion ALI (uCi)	INHALATION ALI uCi)	INHALATION DAC (uCi/mL)
D, all compounds except those given for W	3E+0	6E-1	3E-10
W, oxides, hydroxides and nitrates	-	6E-1	3E-10

[NRC; Table 1, Appendix B to Part 20--Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage. Available from, as of October 15, 2006: http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Polonium-210.html **PEER REVIEWED**

EFFLUENT CONCENTRATIONS ESTABLISHED BY THE NRC FOR SOME POLONIUM COMPOUNDS

RADIONUCLIDE	CLASS	AIR (uCi/mL)	WATER (uCi/mL)
Polonium-203	D, all compounds except those given for W	9E-8	3E-4
	W, oxides, hydroxides, and nitrates	1E-7	-
Polonium-205	D	5E-8	3E-4
	W	1E-7	-
Polonium-207	D	3E-8	1E-4
	W	4E-8	-
Polonium-210	D	9E-13	4E-8
	W	9E-13	-

[U.S. Nuclear Regulatory Commission; Table 2, Appendix B to Part 20--Effluent Concentrations Available from, as of October 15, 2006: http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/Polonium-203.html **PEER REVIEWED**

QUANTITIES OF NRC LICENSED MATERIAL REQUIRING LABELING

RADIONUCLIDE	QUANTITY (uCi)
Polonium-203	1,000
Polonium-205	1,000
Polonium-207	1,000
Poloniu-210	0.1

[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**

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**

Manufacturing/Use Information:

Major Uses:
Small encapsulated sources have been used to eliminate static electricity generated in such processes as paper rolling, the manufacture of sheet plastics and the spinning of synthetic fibers. It is also used on brushes for removing dust from photographic film and in nuclear physics as a source of alpha-particles. Mixtures of polonium with beryllium and other light elements are used as sources of neutrons, and the greatest risk of exposure to polonium occurs during production of these sources. Roasting of phosphate ores in the manufacture of some fertilizers volatilizes the natural polonium found in these ores into an aerosol waste. /Polonium/
[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. V. 78 222 (2001) Part 2] **PEER REVIEWED**

... as a lightweight heat source for thermoelectric power in space satellites /Polonium/
[Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 4-27] **PEER REVIEWED**

Source of alpha-radiation and neutrons, instrument calibration, oil-well logging, moisture determination, power source. /Polonium/
[Lewis, R.J. Sr.; Hawley's Condensed Chemical Dictionary 14th Edition. John Wiley & Sons, Inc. New York, NY 2001., p. 890] **PEER REVIEWED**

Manufacturers:
Oak Ridge National Laboratory, Isotope Business Office, (865) 574-6984, email: isotopes@ornl.gov (in 5 M nitric acid) /Polonium nitrate solution/
[US Department of Energy Isotope Product & Distribution Catalog. Product Menu. Polonium-209. Available from, as of Jan 24, 2006: http://www.ornl.gov/sci/isotopes/catalog.htm **PEER REVIEWED**

Methods of Manufacturing:
Separated from old radium samples or by irradiation of very pure bismuth with neutrons in a nuclear reactor... metallic polonium is then prepared by sublimation of this deposit at about 700 deg C. /Polonium metal/
[Ullmann's Encyclopedia of Industrial Chemistry. 6th ed.Vol 1: Federal Republic of Germany: Wiley-VCH Verlag GmbH & Co. 2003 to Present, p. V30 616 (2003)] **PEER REVIEWED**

Formulations/Preparations:
Polonium-209. with a radiopurity of >99%, is available as the nitrate in microcurie quantities shipped in glass bottles. This material is produced by neutron capture on bismuth-209.
[U.S. Department of Energy; Isotope Catalog Product Menu: Polonium. Available from, as of OCtpber 18, 2006: http://www.ornl.gov/sci/isotopes/catalog.htm **PEER REVIEWED**

Laboratory Methods:

Clinical Laboratory Methods:
In order to study the gastrointestinal absorption and tissue distribution of plutonium, americium and polonium, a variety of analytical techniques are employed. These include ion exchange and solvent extraction leading to alpha spectrometry and liquid scintillation counting. The investigation of low specific-activity environmental or industrial materials, and the very low bioavailability of elements such as the actinides, means that very low levels of activity have to be measured. Contamination at the dissection and tissue separation stage, as well as during the radiochemistry, has to be rigorously avoided. Where very detailed information is needed on the location of radionuclides within tissues, such as in the study of alpha-emitter distribution in the intestine, autoradiography is used. The application and relevance of different measurement techniques to animal studies will be discussed and examples of the results presented.
[Naylor GP et al; Sci Total Environ 130-131: 429-35 (1993)] **PEER REVIEWED**

Analytic Laboratory Methods:
If the redox couple between the metal cathode and the radionuclide to be deposited is positive, the radionuclide will deposit spontaneously. (One side of the disk may be covered with tape or acrylic spray so that deposition occurs only on the other.) That is, it will deposit quantitatively without using any applied potential. Generally, a metal planchet (disk) simply is suspended in the solution that is stirred with a glass stirring rod for a few hours. ... Polonium-210 is an important naturally occurring radionuclide that is often included in environmental studies. Spontaneous deposition onto nickel, silver, or copper disks is the preferred technique for preparing polonium-210 sources for measurement. /Polonium-210/
[Multi-Agency Radiological Laboratory Analytical Protocols Manual Volume II: Chapters 10-17 and Appendix F. (July 2004) p 15-10 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**

Method: DOE-EML Po-02-RC; Procedure: Polonium is equilibrated with Po-208 or Po-209 tracer and isolated from most other elements by coprecipitation with lead sulfide. The sulfide precipitate is dissolved in weak HCl solution. Polonium is quantitatively deposited on a nickel disc. The deposition is very specific and can be carried out in the presence of other radionuclides. The plated disc is counted on an alpha spectrometer to measure chemical yield and activity of the sample. The solution from the deposition may be retained and analyzed for Pb-210.; Analyte: polonium; Matrix: water, vegetation, soil, and Dynaweb filters; Detection Limit: 0.001 Bq/1000 min.
[National Environmental Methods Index; Analytical, Test and Sampling Methods. Polonium (7440-08-6). Available from, as of March 28, 2006: http://www.nemi.gov **PEER REVIEWED**

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

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

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.

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.htmration, and will provide a significant development from the information given in previous ICRP reports on this topic.

Synonyms and Identifiers:

Related HSDB Records:
7439 [IONIZING RADIATION]

Associated Chemicals:
Polonium-210; 13981-52-7

Formulations/Preparations:
Polonium-209. with a radiopurity of >99%, is available as the nitrate in microcurie quantities shipped in glass bottles. This material is produced by neutron capture on bismuth-209.
[U.S. Department of Energy; Isotope Catalog Product Menu: Polonium. Available from, as of OCtpber 18, 2006: http://www.ornl.gov/sci/isotopes/catalog.htm **PEER REVIEWED**

Administrative Information:

Hazardous Substances Databank Number: 7416

Last Revision Date: 20061030

Last Review Date: Reviewed by SRP on 5/11/2006

Update History:
Field Update on 2009-04-16, 2 fields added/edited/deleted
Field Update on 2006-11-30, 1 fields added/edited/deleted
Complete Update on 2006-10-30, 2 fields added/edited/deleted
Complete Update on 2006-10-25, 48 fields added/edited/deleted
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