

Lawrence Livermore National Laboratory
Main Site (U.S. DOE)

Public Comment Release

PUBLIC HEALTH ASSESSMENT

Plutonium 239 in Sewage Sludge
Used as a Soil or Soil Amendment in the Livermore Community

LAWRENCE LIVERMORE NATIONAL LABORATORY, MAIN SITE (U.S. DOE)

LIVERMORE, ALAMEDA COUNTY, CALIFORNIA

EPA FACILITY ID: CA2890012584

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Summary

Potential off-site exposure to plutonium 239 (Pu 239) in sewage sludge released from the Lawrence Livermore National Laboratory (LLNL) to the Livermore Water Reclamation Plant (LWRP) has been identified as a specific community concern. This public health assessment will address that concern by evaluating the public health implications of potential radiological doses from exposures to the Pu 239-contaminated sludge. In order to evaluate the public health implications of the historical distribution of Pu-contaminated sludge to the Livermore community three specific questions are addressed: 1) What concentrations of Pu 239 in sludge would produce doses of public health concern? 2) Were the concentrations of Pu 239 in the sludge distributed to the public by LWRP greater than the levels of potential health concern? 3) Do the available data provide an adequate basis for this public health assessment?

Doses of public health concern are defined as the human intake of Pu 239 (or other radionuclides) via ingestion, inhalation, or external exposure at levels that are capable of causing adverse health effects, such as cancer, other illnesses, or death. The ATSDR minimal risk level (MRL) of 100 mrem/year (above background) is used as a basis for determining radiological doses of public health concern. No adverse health effects have ever been documented from radiological doses of 100 mrem/year or less (above background). The average background radiation dose throughout the US is about 360 mrem/year. The MRL represents a dose of less than 1/3 of normal background.

Several sources of historical monitoring data are available to assess the historic concentrations of Pu 239 in sludge produced at the LWRP. These data include gross alpha concentrations in LLNL effluent to the LWRP, gross alpha concentrations in both digester and processed sludge, and Pu 239 concentrations in soils of disposal areas for contaminated sludge. Past studies have evaluated the potential radiological doses from exposure to Pu 239-contaminated sludge. These studies have assumed different exposure scenarios, including LWRP workers responsible for tilling and spreading the contaminated sludge, residents living adjacent to the sludge disposal area, children playing in sludge-contaminated areas, and adults gardening in and consuming food crops grown in contaminated-sludge soils.

The Pu 239-contaminated sludge, released from the LLNL to the LWRP, and distributed to the Livermore community represents a completed exposure pathway. The route or process of human uptake of the Pu 239 occurs via incidental ingestion and inhalation during the use, transport, or handling of the sludge, or the soil where the sludge was placed, or ingestion of vegetation grown in the sludge-amended soil. The calculation of radiological doses from a long-lived isotope such as Pu 239 is very complex due to the partitioning, retention, and decay of the isotope and each of its decay products within the environment and the different organs in the human body. For this health assessment, radiological doses from exposure to the Pu 239 contaminated sludge are calculated using RESRAD 6.2.1.

A soil Pu 239 concentration (100 percent sludge cover) of 816 pico Curies per gram (pCi/g; 1 pCi= 1×10^{-12} curies; averaged over an entire exposure area or residential yard) is required to produce a dose of 100 mrem/year, as calculated using RESRAD. This calculation includes health-protective exposure factors and includes ingestion of soil and garden crops, inhalation of dust, and external exposure. This calculation also assumes that the contaminated area covers an area of ½ acre to a depth of 6 feet, ½ of the area is unvegetated, and ½ of the resident's food is grown on the contaminated area. Considering that it would take 108 pick-up truck loads of sludge to cover a 1/2 acre lot (to a 3 inch depth), such an exposure scenario, although possible, is very unlikely.

A nearly complete historical record of LWRP gross alpha concentrations for the period of 1960 through 1973 (analyzed by the California Department of Public Health; CDPH) indicates that maximum digester sludge concentrations were less than 300 pCi/g (monthly average values). The average monthly gross alpha concentration of digester sludge measured by LLNL was 606 pCi/g (June 1967; average of digesters 1 and 2). The CDPH digester sludge values show two distinct peaks corresponding with the 1964 and 1967 release episodes (297 pCi/g and 258 pCi/g, CDPH data, respectively). Gross alpha concentrations of LLNL effluent into the Livermore sewer system show the same peaks and provide supplementary data for those periods during which digester concentrations were not collected or analyzed. Collectively, the measured digester sludge data and the LLNL analyzed effluent data indicate that the 1964 and 1967 release episodes represent the worst-case sludge concentrations.

As the concentrations of Pu 239 in processed sewage sludge following the 1964 episode of maximum digester sludge concentration were less than 816 pCi/g, it follows that the maximum Pu 239 concentrations in sludge were below levels of health concern. Although sludge concentrations following the 1967 event are not available, processed sludge gross alpha concentrations following the 1964 release (297 pCi/g digester sludge values) were approximately 60 pCi/g. This indicates that digester sludge gross alpha concentrations are considerably reduced during the treatment process. As processed sludge is further milled and mixed before disposal, it is expected that processed sludge concentrations would be additionally reduced before distribution to the public.

Several areas where contaminated sludge was placed have been sampled for Pu 239 concentrations. These areas include Big Trees Park, residential yards of former LLNL employees, and a test garden on the LLNL facility. Maximum Pu 239 concentrations of these locations were less than 2 pCi/g. Although the initial sludge concentration of most of these areas is unknown, sludge and soil sampling at the LLNL test garden indicated that Pu 239 concentrations in applied sludge are reduced by a factor of more than 5 in the resulting soil. This indicates that tilling and mixing of applied sludge will additionally reduce residential soil Pu 239 concentrations.

Assuming that the available gross alpha concentrations in LWRP sludge and LLNL sewer effluent are a reasonable substitute for direct Pu 239 measurements, the available data clearly indicate that the Pu 239-contaminated sludge does not result in radiological doses of public health concern. Monthly nuclide specific and gross alpha monitoring data for

1973 indicate that gross alpha concentrations overestimate Pu 239 concentrations. Consequently, the use of gross alpha concentrations as a proxy for Pu 239 concentrations is a health protective assumption.

No single data set is adequate for making the above public health determinations. There is not a consistent time series of Pu 239 or gross alpha concentrations in processed sludge. Similarly, there are gaps in the digester sludge measurements, and the LLNL effluent data do not provide specific levels of sludge contamination. However, collectively, the available data do provide an adequate basis for public health assessment. The trends in the different data values support and reinforce the individual data sets. Additionally, the health protective assumptions used in calculating doses provide additional assurance for the health conclusions. The following conclusions are based on our current knowledge of radiation health effects and the data reviewed and evaluated in this health assessment:

1. Pu 239 from LLNL was released to the Livermore sewer system and resulted in the contamination of LWRP sludge which may have been distributed to the Livermore community resulting in areas of above background soil concentrations of Pu 239.
2. Using health protective exposure assumptions, radiological doses from maximum measured concentrations of digester sludge are below levels of health concern. This evaluation assumes that digester sludge gross alpha concentrations represent Pu 239 concentrations and that digester sludge is spread uniformly over an entire residential yard. Pu 239 concentrations of processed sludge distributed to the Livermore community are estimated to be more than 10 times lower than digester sludge concentrations.
3. The available data and evaluations provide an adequate basis for these public health conclusions. Any additional sampling data will be subject to the same types of uncertainties as existing historical data.

Based on the above conclusions, the historic distribution of Pu-contaminated sewage sludge is determined to be **no apparent public health hazard**. No apparent public health hazard means that while exposure may have occurred, or may still be occurring, the resulting doses will not cause sickness or death. As the potential maximum radiological doses from exposures to Pu 239-contaminated sludge are below levels of health concern, ATSDR has no recommendations concerning additional soil sampling in areas of known or unknown sludge distribution. Because the community may still have unresolved concerns about this issue, ATSDR offers the following recommendations:

1. Develop and present educational materials, based on the information included in this public health assessment, to the Livermore community.
2. Continue current monitoring of Pu 239 (and other contaminant) concentrations in LLNL effluent and the LWRP sewage treatment system (as stipulated by existing discharge permit requirements).

Section 1. Introduction and Environmental Pathways

The Lawrence Livermore National Laboratory (Livermore Site; hereafter referred to as LLNL), is a multi-program research facility owned by the U.S. Department of Energy (DOE) and operated by the University of California. The LLNL is a science, technology, and engineering facility with a special focus on nuclear weapons research and development. Other areas of research include arms control and treaty verification control technology, energy, the environment, biomedicine, the economy, and education (DOE 1992).

LLNL was placed on the Superfund National Priority List (NPL) in 1987 on the basis of volatile organic compounds (VOCs; trichloroethylene, tetrachloroethylene, chloroform, 1,1-dichloroethylene, and others) in monitor wells and nearby drinking water wells (LLNL 1990). The Agency for Toxic Substances and Disease Registry (ATSDR) is required to conduct a public health assessment of all facilities proposed for the NPL.

During the course of the LLNL public health assessment process, potential off-site exposure to plutonium 239¹ (Pu 239) in sewage sludge released from the LLNL to the Livermore Water Reclamation Plant (LWRP) was identified as a specific community concern (CDHS, in review). In response to this concern, ATSDR has prepared this public health assessment to determine if exposure to Pu 239-contaminated sludge could have occurred at concentrations likely to result in adverse health effects.

Processed sewage sludge from the LWRP was distributed for use as a soil amendment to municipal agencies from at least 1958 until 1976 and to the public from at least 1958 until 1973 (CDHS 2002). The LLNL facility has been discharging wastewater to the LWRP since at least 1959. Contaminant concentrations in effluent releases (including Pu 239) from LLNL to the municipal sewer system have been regulated by federal discharge limits and/or state and local permit requirements with related compliance monitoring since at least 1959 (LRL 1960-1970).

Radiological releases from LLNL to the sewer system during this period occurred as both routine low-level discharges and several higher concentration episodic events, which have resulted in Pu 239 contamination of the sludge processed and distributed by the LWRP. Although LLNL has monitored their sewage effluent since at least 1959, there has not been regular monitoring of the processed sewage sludge. Additionally, permit requirements, discharge limits, monitoring and reporting procedures have changed over

¹ Plutonium will be present as several different isotopes. Typical weapons grade plutonium consists of about 94% Pu 239 and about 6% Pu 240 with much lower percentages of Pu 238, 241, and 242 (NAS 1995). Standard analyses using alpha spectroscopy will not differentiate between Pu 239 and Pu 240. However the dose conversions factors for the Pu 239 and Pu 240 isotopes are equal so that differences in the relative abundance will not change the resulting dose estimates. Due to the much higher proportion of Pu 239, this document will refer to combined Pu 239/240 measurements as Pu 239. A glossary of technical terms is included as Appendix 1.

time which creates difficulties in interpreting Pu 239 concentrations in sludge during this time period. These changes, along with a lack of direct monitoring of processed sewage sludge have created concerns in the Livermore community about potential exposures to the Pu 239-contaminated sewage sludge that may have been used as a soil amendment for public and private properties.

In order to evaluate the public health implications of the historical distribution of Pu-contaminated sludge to the Livermore community three specific questions must be addressed: 1) What concentrations of Pu 239 in sludge would produce doses of public health concern? 2) Were the concentrations of Pu 239 in the sludge distributed to the public by LWRP greater than the levels of potential health concern? 3) Do the available data provide an adequate basis for this exposure assessment and the resulting public health conclusions? Doses of public health concern are defined as the human intake of Pu 239 (or other radionuclides) via ingestion, inhalation, or external radiologic exposure at levels that are capable of causing adverse health effects, such as cancer, other illnesses, or death.

With regard to the Pu 239 concentration required to produce a dose of public health concern, in 1976, Lawrence Radiation Laboratory (now known as LLNL) staff published a study evaluating the use of Pu-contaminated sludge as a soil conditioner for food crops (Myers et al. 1976). Although the radiation dose estimated in that study is well below a level of health concern, it is possible that historic Pu 239 concentrations in LWRP sludge were higher than those used to estimate doses in the Myers et al. (1976) study. This document evaluates the historic monitoring data using a current exposure assessment model to determine if the concentrations of Pu 239 in sludge could have reached levels of public health concern.

Specifically, this public health assessment will evaluate whether potential maximum Pu 239 concentrations in sludge following the 1964 and 1967 episodic releases could have exceeded the concentration necessary to produce a dose of public health concern. Specific analytical measurements of Pu 239 (and Americium 241; Am 241²) concentrations in the LWRP sludge during the 1967 to 1969 timeframe are currently not available. However, there are time-specific gross alpha data, which can provide limits on the potential maximum Pu 239 concentrations. This document will use that data to estimate the potential maximum Pu 239 sludge concentrations for the 1960-73 timeframe (including the assumptions underlying those estimates) and compare those concentrations with a concentration capable of producing a radiological dose of public health concern (question 1, above).

This document will also evaluate information related to the radio-toxicity of plutonium. Specifically, this assessment will summarize the health effects studies from plutonium

² The releases may have contained an unknown proportion of Am 241. In typical weapons-grade plutonium, Am 241 comprises less than 1 % of the activity (NAS 1995) and does not have a significant contribution in the resulting dose. This assessment will focus on Pu 239 as the primary dose constituent.

exposures, the doses at which those health effects occurred, and compare those doses with various Pu 239 soil concentrations and soil screening values.

The question of whether the available data provide an adequate basis for this public health assessment (question 3, above) presents a significant challenge in collecting and interpreting historical data. The currently required practices of data collection, analytical methods, quality assurance, and data management cannot be assumed for samples collected and analyzed 30 to 40 years ago. Rather than trying to impose those current requirements on the historic data, the evaluation of data adequacy for this assessment will focus on whether disparate data sets lead to similar and consistent interpretations. If different data sets produce similar results and support consistent conclusions, this assessment will conclude that the available data adequately measure past and current exposure conditions and provide a satisfactory basis for the public health evaluation.

The premise of this public health assessment is that Pu 239 concentrations in sludge following the 1964 and 1967 releases represent worst-case conditions. If estimated maximum doses from exposure to contaminated sludge from the worst-case conditions are below levels of public health concern, it follows that doses from all lesser exposures are also below levels of public health concern. Available monitoring data will be further evaluated to determine if sludge concentrations following the 1964 and 1967 releases do indeed represent worst-case conditions. Limitations and assumptions underlying the available data and exposure models will be noted.

Site Description and History

The LLNL site is in southern Alameda County, California, and approximately 40 miles east of San Francisco (Figure 1). The LLNL is about three miles east of the central business district of the City of Livermore but directly abutted by residential properties to the west, commercial and industrial properties to the north, agricultural and residential land to the east, and the Sandia National Laboratory to the south. LLNL also operates the LLNL 300 site near Tracy, California (about 12 miles east of the main site). Operations and potential contaminant releases of the 300 Site will be addressed in a separate public health assessment.

The LLNL main site, including a buffer zone acquired in 1989, covers an area of approximately 821 acres in the southeastern portion of the Livermore Valley. In 1942, the U.S. Department of the Navy acquired 681 acres of agricultural and ranch land to establish the Livermore Naval Air Station. Although the original use of the Naval Air Station was for flight training, by October 1944, aircraft assembly, repair, and overhaul were conducted at the Livermore NAS. From 1945 until the Livermore NAS was deactivated in 1946, extensive aircraft repair and assembly occurred at the site. The site was occupied by the Atomic Energy Commission (AEC) in 1950 with formal transfer of the property in 1951. The AEC, its successor agencies and ancillary entities have occupied the site for defense-related research. In 1952, the site was established as a separate part of the University of California Radiation Laboratory. In 1971, the

Livermore site became the Lawrence Livermore Laboratory, and in 1979 was renamed by Congress as the Lawrence Livermore National Laboratory. LLNL is operated by the University of California under contract with the U.S. Department of Energy.

In 1992 DOE published the "Final Environmental Impact Statement and Environmental Impact Report for Continued Operation of the Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore". This document includes a detailed statement of LLNL operations and facilities. The information from that report outlining LLNL operations and facilities will not be reproduced here, but will be referenced as appropriate to define environmental releases and potential community exposures to chemical and radiological materials.

Background and Previous Studies

In order to assess the potential concentrations of Pu 239 in sludge processed by the LWRP, it is necessary to have a basic understanding of how a wastewater treatment plant operates. In an activated sludge system, such as the LWRP, wastewater enters the system through a series of screens where large debris is filtered. Primary treatment consists of gravitational separation by skimming of floating materials and settling of heavier particles and sediment. Primary treatment removes 45% to 50% of the waste materials in the initial plant influent. Solid materials from the primary separation step are pumped into the sludge digesters where bacteria break down and decompose the sludge (referred to as digester sludge). Water that has passed through the primary sedimentation tanks still contains significant amounts of waste materials in dissolved or very fine solid forms. This water undergoes secondary treatment by exposure to microorganisms that consume the waste material and convert it into biomass. This biomass is filtered from the water and is also pumped to the digesters as sludge.

Although waste solids remain in the digesters for approximately 28 days, new and re-processed sludge is pumped into and out of the digesters on a daily basis (J Dupont, personal communication; 7/09/02; also see Appendix 2). Solid materials produced from the digester process are pumped into drying beds or lagoons where water can further evaporate from the wet sludge. The sludge lagoons and/or drying beds accumulate sludge from the digesters for periods of 1 to 5 years (hereafter referred to as dried or processed sludge). After drying, the remaining solid, dried sludge is transported to disposal areas, mixed with soil to enhance drying, and historically, provided to the public for use as a fertilizer or soil amendment.

Plutonium has a very low solubility in water. This means that very little of the Pu 239 present in the sewer effluent from the LLNL will occur in a dissolved form, but is much more likely to occur as a solid particle or adsorbed onto a solid particle. Within the LWRP, Pu 239 will rapidly accumulate with the solid materials in sludge. As both gross alpha and isotope specific monitoring of the liquid effluent released from the LWRP are typically non-detections (both historic and current analyses), it follows that the Pu 239 entering the treatment plant remains in solid form in the sludge component.

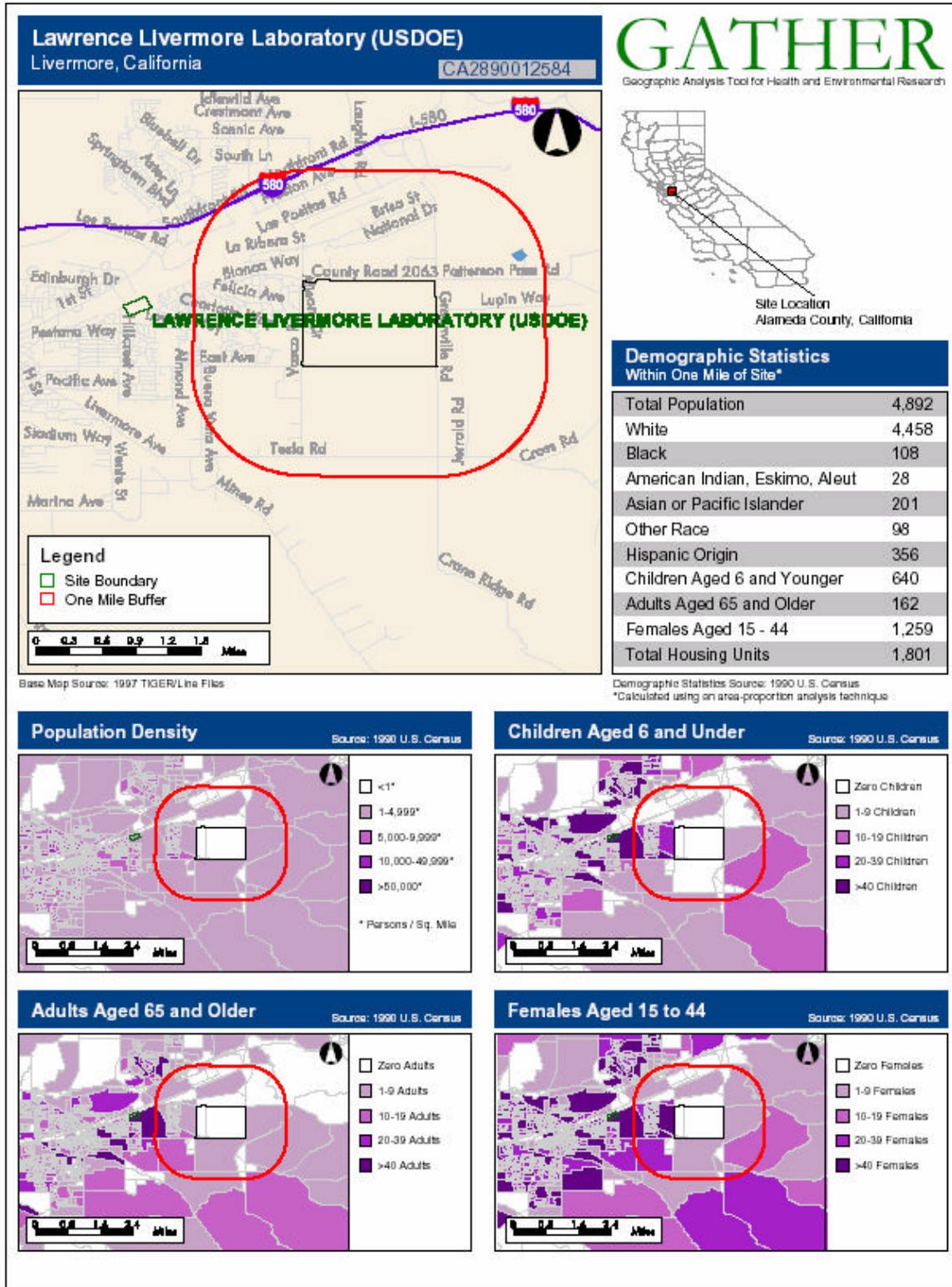


Figure 1. This map shows the LLNL within Livermore community and population characteristics surrounding LLNL facility. These population characteristics are not specifically related to potential sludge exposures (see the following section).

Past and ongoing monitoring reports document the plutonium releases to the LWRP and concentrations in the processed sludge. Although there are no historic isotope-specific data documenting the past Pu 239 sludge concentrations following the 1967 release, there are data which can be used to put an upper limit on the possible concentrations. Following the May-June 1967 release of plutonium to the LWRP, LRL staff initiated an enhanced sampling effort at the LWRP. Some results of that sampling effort are reported in a letter and attached memorandum from D.C. Sewell (LRL) to E.C. Shute (U.S. Atomic Energy Commission) dated August 22, 1967 (included as Appendix 2).

Of particular interest are the semi-annual and annual Lawrence Radiation Laboratory (LRL: prior name of LLNL) environmental reports for the years before and after the accidental Pu/Am release in 1967 (LRL 1960-70; LLL 1971-73). Before 1967, the reports indicate values of gross alpha concentrations of monthly sludge and liquid effluent samples. For 1965 and 1966 the gross alpha activities in dried sludge ranged from 17 to 60 picocuries³ per gram (pCi/g). Liquid effluent samples (from the oxidation ponds or unspecified location) ranged from 7 to 26 pCi/liter.

In addition to the sewage monitoring data collected by the LLNL, the California Department of Public Health (prior name of California Department of Health Services; CDHS), Bureau of Radiologic Health historically conducted radiological monitoring of public sewage treatment facilities. Monthly data (gross alpha) from the LWRP around the time of the May 1967 accidental Pu 239 release indicate maximum digester sludge concentrations in May and June (1967) of 258 pCi/g and 229 pCi/g (respectively). This data set includes monthly gross alpha concentrations⁴ of LWRP digester sludge from 1960 to 1969 (CDHS, 1960-1969). The available monitoring data will be presented and summarized in the following section on "Maximum Pu 239 Concentrations in LWRP Sludge."

A number of studies and monitoring reports have been conducted and published to assess the potential health effects from the distribution of the plutonium-contaminated sludge. These studies include the Myers et al. (1976) study that specifically evaluated the radiological dose produced by using Pu 239-contaminated sewage sludge as a soil amendment on a residential garden. This study includes direct measurement of Pu 239 concentrations in sludge, the sludge-amended soil, air during tilling operations, and in food products grown in the sludge-amended soil.

³ The gross alpha concentrations are originally reported in disintegrations per minute per gram (dpm/g). Liquid effluents are presented as dpm per liter. Dpm is converted to pCi using the following conversion factors. 1 dpm = 60 dps; 1 dps = 1 Bequerel; 1 Bequerel = 27 pCi.

⁴ Although we have no information on the historic CDHS, Bureau of Radiological Health gross alpha analytical procedures, there is no a priori reason to doubt the validity or utility of their data. We are currently trying to determine their specific procedures.

In addition to the Myers et al. study evaluating potential exposures to home gardeners, Balke (1993) conducted an evaluation of potential exposures to workers at the LWRP facility and to residents living directly downwind of the contaminated sludge disposal area. This study also included reviews of directly measured Pu 239 concentrations in contaminated sludge, soil from the contaminated sludge disposal area, and air directly downwind of the sludge disposal area. Fifty year radiological doses were calculated for residents living adjacent to the contaminated sludge disposal area and to a hypothetical LWRP worker that tractor-tilled the contaminated sludge for 520 hours per year for 50 years (the frequency of tilling operations is based on LWRP work schedule information).

Potential exposure to the Pu 239-contaminated sewage sludge was also evaluated in a health consultation (ATSDR 1999a) on "Plutonium Contamination in Big Trees Park." The "Evaluation of Radiation Dose" in this health consultation calculated the dose to a pica child⁵ playing in the area of the maximum measured Pu 239 concentration (1.02 pCi/g) for 2000 hours per year (eight hours per day for five days per week for 50 weeks per year). The exposure calculation also used health protective assumptions about the plutonium particle sizes and solubility and determined that the estimated committed effective whole body dose would be less than 1 millirem per year (mrem/yr). MacQueen et al. (2002) indicate that a more realistic exposure assessment would use an average Pu 239 concentration from the Big Trees Park area rather than the maximum concentration from one sample. The resulting dose would be about 8% of the dose calculated using the maximum concentration.

Based on recommendations in the Health Consultation, additional sampling in Big Trees Park was conducted in 1998. The results of that additional sampling were reported in another Health Consultation (ATSDR 2000) and an LLNL report (MacQueen et.al. 2002). Both the sampling results and doses calculated from those samples are similar to those from the 1999 Health Consultation. In addition to the re-sampling of Big Trees Park, the 2000 Health Consultation (ATSDR 2000) reported some historical results of 1973 analyses of the yards of LLNL employees that had obtained and used LWRP sewage sludge. While the Pu 239/240 concentrations of those yards are below levels of health concern (maximum value of 1.8 pCi/g), the results do indicate that contaminated sludge was distributed to the Livermore community.

A variety of historical monitoring data is available to assess the historic concentrations of Pu 239 in sludge produced at the LWRP. These data include gross alpha concentrations in LLNL effluent to the LWRP, gross alpha concentrations in both digester and processed sludge, and Pu 239 concentrations in soils of disposal areas for contaminated sludge. Past exposure studies have evaluated the potential radiological doses to Pu 239-contaminated sludge. These studies have assumed different exposure scenarios, including LWRP workers responsible for tilling and spreading the contaminated sludge,

⁵ A pica child is a 2-3 year old child with a craving for unnatural food such as soil or ashes. Although the prevalence of this type of behavior is unknown, the EPA recommends that pica ingestion rates only be used for acute (1 to 14 day) exposure assessments (EPA 1999).

residents living adjacent to the sludge disposal area, children playing in sludge-contaminated areas, and adults gardening in and consuming food crops grown in contaminated-sludge soils.

Exposure Pathways

A release of a chemical or radioactive material into the environment does not always result in human exposure. For an exposure to occur, a *completed exposure pathway* must exist. A completed exposure pathway exists when all of the following five elements are present: 1) a source of contamination, 2) an environmental medium through which the contaminant may be transported to 3) a point or area of human exposure, 4) a route or process of human uptake (ingestion, inhalation, etc.), and 5) an exposed population. A *potentially completed pathway* exists when one or more of the above elements are missing or unknown, but available information indicates that exposure is, or will be likely. An *incomplete exposure pathway* exists when one or more the five elements are missing and available data indicate that human exposure is unlikely.

The Pu 239-contaminated sludge, released from the LLNL to the LWRP, and distributed to the Livermore community represents a completed exposure pathway. Although there are still questions about which specific individuals or municipal agencies may have received the sludge, the finding that Pu 239-contaminated sludge was distributed to the tree wells at Big Trees Park proves that the sludge has been placed in areas of human exposure. Also, because the distribution of sludge from the LWRP to the public was a standard practice, it is further assumed that contaminated sludge was similarly distributed to the Livermore community.

The route or process of human uptake of the Pu 239 would occur via incidental ingestion and inhalation during the use, transport, or handling of the sludge, or the soil where the sludge was placed, or ingestion of vegetation grown in the sludge-amended soil. Although the specific people who may have been exposed to the Pu 239-contaminated sludge are unknown, more specific information concerning the human uptake of the Pu 239 will be presented in the following section on exposure assessment.

Exposed Population

There is no way to precisely determine how many members of the Livermore community may have been (or are) exposed to soil with elevated concentrations of Pu 239 from LLNL-released and LWRP-processed sludge. There are anecdotal references to a logbook maintained by LWRP as a record of sludge distribution. If available, this logbook could provide a specific reference to who may have obtained and used sludge as a soil amendment. Despite extensive searches, this logbook has not been located.

In lieu of a quantitative estimate of the number of people potentially exposed to contaminated sludge, this evaluation will focus on the exposure conditions or scenarios

that would lead to the highest doses or worst-case exposure conditions. Although it is not expected that any member of the Livermore community would include all of the conditions or exposures of the potential worst-case scenario, many Livermore residents could have been exposed to Pu 239-contaminated soil.

Section 2. Community Concerns Related to Plutonium in Sewage Sludge

Community health concerns about the LLNL-related contamination are summarized in a health consultation prepared by the California Department of Health Services (CDHS 2001). This health consultation describes the Site Team formed to prioritize community health concerns and lists the community health concerns regarding LLNL and the processes by which those concerns have been collected. Concerns about plutonium contamination of LWRP sewage sludge are repeated in several portions of the health consultation and are (as included in Appendix A of that document): “Residential distribution of plutonium contaminated sewer sludge from the Livermore Water Reclamation Plant” which is listed as an exposure concern and “Financing of plutonium testing in yards that received sewer sludge from the water reclamation plant” which is listed as a procedural concern. Evaluation of the distribution or exposures to plutonium-contaminated sewage sludge are not included in the Site Team Priority Concerns (Appendix B of the Health Consultation), but may be related to “Biomonitoring for plutonium” (item 9 of 9 in Appendix B).

In addition to the above specific concerns about plutonium in sewage sludge, there are a number of references to concerns about plutonium in Big Trees Park and other areas throughout the Livermore community. As it has been determined that the plutonium in Big Trees Park and other municipal properties is the result of distribution of plutonium-contaminated sewage sludge as a soil amendment (ATSDR 2000; MacQueen et.al. 2002) many of the concerns about plutonium soil contamination are directly or indirectly related to the distribution of contaminated sewage sludge.

In September of 1999, ATSDR conducted a public availability session at the Arroyo Seco Elementary School. The session was held to provide community members an opportunity to tell ATSDR representatives about any concerns they may have related to LLNL contaminants, specific health concerns, or issues related to the ATSDR’s conduct of the public health assessment. Four ATSDR representatives listened to and took notes from 6 members of the Livermore community (about 30 people attended the session, but only 6 provided specific comments). Comments related to exposure to, and distribution of, the contaminated sewage sludge were presented to, and noted by, the ATSDR representatives.

In response to these concerns, CDHS formed a “sludge working group” (SWG) in March 2000 to develop a community-based process for addressing those concerns (CDHS 2002). The group, which met periodically in 2000 and 2001, consisted of representatives of state and local agencies and members of local and regional special interest groups. Most of the members of the SWG are also members of the Site Team (described above).

During a conference call with ATSDR representatives (July 30, 2002), members of the SWG described several specific concerns related to the Pu 239-contaminated sludge issue. These concerns include: an overall perception that there are insufficient data available for evaluating the public health issues related to historic sludge distribution and exposure, the SWG also had concerns about the use of the ATSDR minimal risk level

(MRL) used to evaluate doses of public health concern, and the need to include potential doses to children as part of the exposure assessment in this document. Those concerns are explicitly addressed in this PHA.

The remaining portions of this public health assessment will address the community's concerns by providing estimated radiological doses from exposure to Pu 239-contaminated sewage sludge, compare those exposure doses with doses that have caused sickness or death, and determine whether available monitoring and exposure data are adequate for evaluating potential public health effects.

Section 3. Exposure Assessment of Pu 239-Contaminated Sludge

Exposure Assessment Method

As indicated in the previous section on “Background Information and Previous Studies” there have been several evaluations of the concentrations of Pu 239 in LWRP sludge and radiological dose estimates from exposure to the contaminated sludge. Several of the studies have used 2.5 pCi/g as a soil screening guidance value. The derivation and significance of this soil screening value will be discussed in the following section on “Public Health Implications”. This exposure assessment will calculate radiological doses using a Pu 239 concentration of 2.5 pCi/g in the soil of a ½ acre homesite (the EPA default exposure area).

The calculation of whole body and organ specific radiological doses from a long-lived isotope such as Pu 239 is very complex due to the partitioning, retention, and decay of the isotope and each of its decay products within the environment and the different organs in the human body. This complexity is resolved through the use of analytical models that track and sum the doses (or radioactive decays or relative risks) across the environmental pathways and through the human body. For this health assessment, radiological doses from exposure to the Pu 239 contaminated sludge are calculated using RESRAD 6.2.1 (ANL 2001). RESRAD is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials. RESRAD 6⁶ represents the sixth major version of the RESRAD code since it was first issued in 1989. RESRAD has been used for deriving limits for radionuclides in soil by the U.S. Environmental Protection Agency (EPA), the U.S. Army Corps of Engineers, U.S. Department of Energy (DOE; and its contractors), and the U.S. Nuclear Regulatory Commission (NRC).

The use of RESRAD 6 requires specification of several dozen parameters or use of default values for those parameters. The default values are used for all parameters except area of contaminated zone (1/2 acre) and average annual wind speed (3.89 m/sec). The above parameters were adjusted to agree with values recommended in the EPA Exposure Factors Handbook (EPA 1999) or area-specific meteorological conditions (average wind speed).

The RESRAD 6 dose calculation includes dose contributions from external gamma exposure, inhalation of dust/soil, food, milk, and meat ingestion, drinking water, and soil ingestion. Dose contributions from radon are not included.

⁶ The default Pu 239 dose coefficients in RESRAD 6 are based on ICRP Publication 67 (1993). Those dose coefficients have been updated by use of values from ICRP Publication 72 (1996).

Exposure Scenarios

An exposure scenario is a quantitative description of the types of human behaviors and activities during which exposure to a contaminated material or substance might occur. A scenario description includes the frequency with which an exposure activity occurs, the duration of each episode of the activity, and the types of potential uptake, such as ingestion or inhalation that occur during each exposure activity. The exposure scenarios provide the basis for calculating a quantitative estimate of the amount of contaminated material someone may have taken into their body. The quantitative estimate of exposure is called the exposure dose and is usually expressed per unit time (day or year). The radiological doses presented in the following section are expressed as millirem per year (mrem/yr).

Previous studies have identified and evaluated several exposure scenarios. These scenarios include the evaluation of exposures that may occurred from use of contaminated sewage sludge as a soil amendment to a residential garden, exposures to a LWRP worker conducting sludge land spreading operations, and a resident living directly adjacent to the area of land spreading operations. Collectively, these scenarios represent the activities and behaviors where direct contact and uptake of contaminated sludge is most likely and therefore present the highest potential for significant exposure. Although no specific individuals can be associated with each of these scenarios, each is likely to have occurred such that the exposure pathway will be considered to be complete for each scenario.

The most health protective exposure scenario is to assume that an entire residential lot or yard has been covered with contaminated sludge. In order to calculate an estimated exposure dose for this residential exposure scenario, it is necessary to make assumptions about the exposure factors during which exposure to contaminated sludge could occur. The basis for this scenario is a 1/2 acre residential lot with uniform contamination over the entire area to a depth of two meters⁷. Exposure occurs for 350 days per year. The exposure factors include the frequency and duration of exposure activities, as well as the specific rates of contaminant uptake (e.g., breathing and ingestion rates) during those activities. The exposure factors used in estimating the integrated dose for this assessment are primarily RESRAD default values which are similar to values from the Exposure Factors Handbook developed by the U.S. Environmental Protection Agency (EPA 1999) or from the EPA Soil Screening Guidance for Radionuclides (EPA 2002).

All intake rates used in this assessment are based on long term (30 to 70 year) exposures. In some cases it may be important to consider intake rates and behaviors of children if

⁷ A 1/2 acre residential lot is used as the basis for comparison and dose calculation because it is the area used as an underlying assumption in the derivation of the US EPA Preliminary Remedial Goal (PRG) of 2.5 pCi/g for Pu 239. A two meter depth is used to approximate the “infinite slab” assumption underlying the EPA PRG. A more detailed evaluation of the assumptions underlying the development of the PRG is included in Appendix 6.

childhood activities lead to potentially higher doses. In this case, childhood activities would only occur for a limited portion of the overall 70 year exposure duration. Also, the Pu 239 dose conversion factors specifically include provision of body and organ weights that are corrected for aging and growth. Additionally, the exposure scenarios assume activities such as gardening and outdoor workers that have very high soil exposure and intake rates. Consequently, the high intake rates, the Pu 239 dose conversion factors, and long exposure durations are protective of any potential exposures to children and adults.

Exposure Factors	Intake Rates and Durations
Ingestion of soil	70 year rate- 100 mg/day for 70 years
Inhalation of fugitive dust	Inhalation rate of 20 m ³ /day One half of lot is unvegetated (bare soil) Air/soil concentration ratio is 1.0e-4 g/m ³ * 68% of time is spent indoors (on site) 7.3% of time is spent outdoors (on site) 24.7% of time is off site Indoor air loading is 40% of outdoor air
Ingestion of food grown in home garden	100 kg/year vegetable and fruit ingestion rate 14 kg/year leafy vegetable ingestion rate One half of all produce consumed is grown in home garden
Exposure Frequency	350 days per year for 30 or 70 years
<p>Table 1. The duration and intake rates for potential exposures to Pu 239-contaminated sludge spread uniformly over an entire residential yard and garden. All exposure frequencies and intake rates are RESRAD defaults and similar to values from the Exposure Factors Handbook (EPA 1999).</p> <p>* The air/soil concentration ratio is the average mass loading of the airborne contaminated soil particles in g/m³. The default mass loading (1.0e-4 g/m³) is a conservative estimate that takes into account short periods of high mass loading and sustained periods of normal activity on a typical farm (ANL 2001).</p>	

Estimated Pu 239 Doses from Pu 239/240 Contaminated Soil

The results of the RESRAD dose estimations are presented in Figure 2. This chart shows the combined dose for all nuclides and all pathways as 0.31 mrem/year for a time period of 1 to 70 years. This dose estimate assumes that an entire residential yard and garden are contaminated with Pu 239 and Pu 240 at a combined average concentration of 2.5 pCi/g.

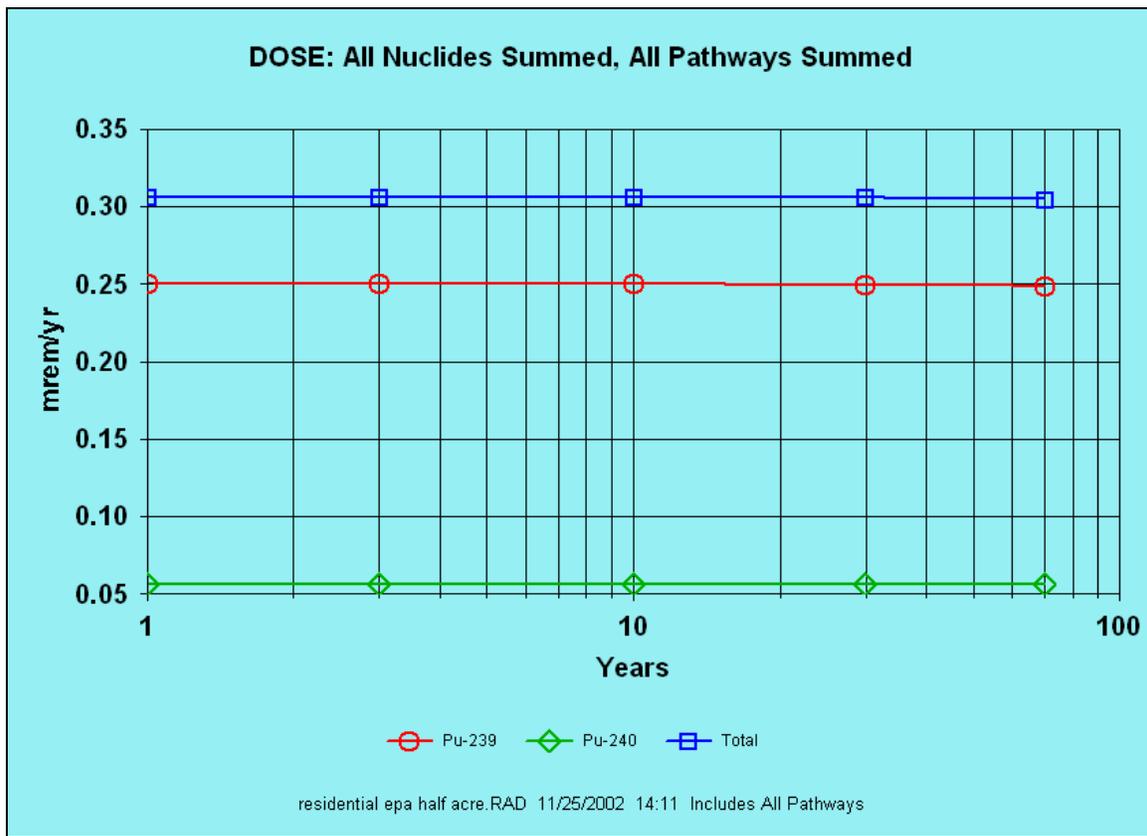


Figure 2. The annual Effective Dose Equivalent (whole body; EDE) from a residential exposure scenario to an average soil Pu 239/240 concentration of 2.5 pCi/g is 0.31 mrem/year. This scenario assumes ½ of annual fruit, vegetable, and grain consumption comes from a home garden. The relative contributions of the Pu 239 and Pu 240 components do not affect the total dose as those nuclides have identical dose coefficients. The relative Pu 239 and Pu 240 composition shown in this figure and Appendix 3 are based on average compositions of weapons grade plutonium (NAS 1995).

Note that the estimated Pu 239 dose (Annual Effective Dose Equivalent; EDE) is constant over a 70 year time period. The effective dose equivalent from year one is the same as that from year 70. The output of the RESRAD model run is included as Appendix 3. The public health implications of a radiological dose of 0.31 mrem/year are discussed in the following “Public Health Implications” section. Following sections will

evaluate this dose assessment with different concentrations of Pu 239 including the estimated maximum concentration based on measured gross alpha concentrations.

Maximum Pu 239 Concentrations in LWRP Sludge

As previously stated there are no isotope-specific measurements of Pu 239 in sludge that may have been distributed to the Livermore community in the 1967 to 1970 timeframe. However, there is a relatively complete record of monthly gross alpha measurements of sludge from the LWRP digester for the 1960 to 1969 period (CDPH data; CDHS 1960-1969). In addition, there are measurements of gross alpha concentrations in sewer effluent leaving the LLNL facility, gross alpha concentrations in digester and dried sludge, and estimates of annual gross alpha releases to the sewer system from LLNL. Gross alpha concentrations from several of these data sources are plotted in Figure 3. The data underlying this chart are included in Appendix 4.

The gross alpha concentrations in Figure 3 span the years from 1960 to 1973 and include monthly, 6-month, and annual averages for sludge from the digesters and drying beds (dried sludge). The values plotted in Figure 3 represent gross alpha concentrations as picoCuries per gram (pCi/g) for dried sludge from the digesters or drying beds, pCi/Liter (pCi/L) for liquid effluent data, and Ci/year for annual releases to the sewer system (on the right hand scale). The annual release values for 1973 are Pu 239 concentrations, values for all other years are gross alpha concentrations.

Figure 3 shows several significant trends related to historic gross alpha concentrations in sewage effluent (from LLNL) and gross alpha concentrations in the digesters and drying beds. The most significant trend is that the 1967 Pu 239 release is consistently tracked by all of the data types and it is obviously the most significant short or long term release event. Figure 3 shows that the 6 month average sewer effluent data and the annual release data both track the monthly digester sludge values. This indicates that the semi-annual or annual data averages capture and record a short term event, such as the May-June 1967 Pu 239 release.

Note that the digester sludge value from June 1964 is the highest CDPH digester sludge value (296.9 pCi/g). Also note that the sewer effluent and annual release values do record a release event in the 1964 timeframe, but that the effluent spike is only about 1/3 that of the 1967 event. Another important trend from the 1964-1965 timeframe is the relationship between the elevated effluent release and digester sludge values and the subsequent increase in the dried sludge gross alpha concentrations. Dried sludge gross alpha concentrations increase about 8 to 12 months after the May-June 1964 digester and effluent spikes.

This time lag represents the processing time required for LLNL effluent to be processed through the treatment plant and for placement of the resulting sludge in the drying beds. It is also important to note that, because of the time lag and the mixing and dilution that occur in the sewage processing, the gross alpha concentrations in the dried sludge are much lower than the digester concentrations. The May-June 1964 digester spike reaches

gross alpha concentrations of 297 pCi/g while the maximum drying bed sludge values are only 60 pCi/g with a 10-12 month lag period.

Digester sludge concentrations decrease over several months after a release event, such as the May-June 1967 Pu 239 release. As shown in Figure 3, it takes about 6 to 8 months for digester concentrations to return to pre-release values. From high concentrations of 258 pCi/g in May 1967 and 229 pCi/g in June, monthly values decline relatively rapidly with concentrations less than 100 pCi/g by October 1967 and less than 50 pCi/g by January 1968. This 6 to 8 month decline in digester gross alpha concentrations reflects the dilution process that occurs within the digesters.

In addition to the gross alpha concentrations measured by CDPH, LLNL also collected and measured gross alpha concentrations in sludge from the LWRP digesters (1 and 2) and from the oxidation pond. In the LLNL annual or semi-annual environmental reports (LRL or LLL 1960-73) these values are reported as 6 month or annual average values. LLNL has recently re-calculated the monthly values that underlie the annual or semi-annual reported values (McConachie personal communication, January 28, 2003). These values are included in Appendix 4. The LLNL measured digester concentrations are not plotted on Figure 3 because we currently have a limited number of data points for the time period. We will continue to evaluate these data as they become available.

For the 1967 measurements, the LLNL gross alpha sludge values (the average of digesters 1 and 2) are larger than the gross alpha concentrations measured by CDPH. The June 1967 value measured by CDPH is 229 pCi/g while the LLNL value for the same month is 606 pCi/g (digester 1 and 2 average). It is not known if these differences are due to the way the samples are collected and composited (such as a combination of digester 1 and 2 samples or the time period over which the samples are composited), analytical procedures, or a combination of these and other factors. Although there are consistent differences in the absolute values of these measurements, both data sets show similar peaks and trends over time. Following references to specific digester sludge values will state whether the measurements were analyzed by the CDPH or by the LLNL.

The distribution of these gross alpha data values indicates that the release of Pu 239 into the LWRP sewer system is documented by measurements of gross alpha concentrations in digester sludge samples, sludge samples from the drying beds, and LLNL sewer effluent data. Because the measurement of gross alpha concentrations entails counting all alpha decays, it necessarily includes a variety of radionuclides, such as uranium, thorium, radium, and other alpha emitters. If the analysis process is accurately measuring gross alpha concentrations, the resulting gross alpha measurements are a health-protective estimate of Pu 239 concentrations.

Figure 4 presents one year (1973) of monthly digester gross alpha concentrations (analyzed by LLNL) and the relative proportions of Pu 239 and Pu 238 in that sludge. This figure shows that, during 1973, the Pu 239 concentrations in the LWRP digester represented about 2% to 4% of the overall gross alpha concentration. The gross alpha measurements are not a specific measurement of Pu 239 concentrations because typical

gross alpha measurements detect all alpha decays (within a specified energy range). Gross alpha measurements within the energy range used at LLNL includes isotopes, such as uranium 235 and 238 in addition to Pu 239. Because Pu 239 has a higher radio-toxicity than the other common alpha decay nuclides, assuming that all alpha decays occur as Pu 239, is a health protective estimation of the total radiological concentration.

During a specific release of Pu 239 (such as the May 1967 release), the relative concentration of the Pu 239 will increase. For the 1967 release, most of the increase in the gross alpha concentration was probably due to Pu 239. However, the baseline contribution from other alpha-emitting radionuclides will still be present, such that the gross alpha concentrations will be a health protective estimate of the specific Pu 239 concentrations.

It should be further noted that, as shown in Figure 3, maximum Pu 239 (or gross alpha) concentrations in digester sludge will overestimate the Pu 239 concentrations in the sludge lagoons or drying beds. The sludge lagoons receive sludge for periods of a year or more for drying and mixing. Consequently, short periods of high concentration sludge will be mixed with a much greater volume of lower concentration sludge. Therefore, use of the maximum gross alpha concentrations of monthly maximum values from the sludge digesters as an indicator of maximum Pu 239 concentrations in processed sludge is very health protective. Any sludge that may have been distributed to the public would have had significantly lower Pu 239 concentrations as indicated by gross alpha concentrations of dried sludge (Figure 3).

Although this evaluation of gross alpha and Pu 239 concentrations in LWRP sludge cannot provide specific Pu 239 concentration values for LWRP sludge, it does provide a reliable upper limit on what those concentrations could have been. The maximum sludge Pu 239 concentrations could not have exceeded the gross alpha value of 674 pCi/g (as measured by LLNL) in digester sludge samples and were most likely lower than 100 pCi/g.

Average values in soils to which the sludge was added would necessarily be lower than sludge values. In the Myers et.al. (1976) study, the addition of 13 cubic meters (17 cubic yards) of sludge, with an average concentration of 2.8 pCi/g, resulted in a soil Pu 239 concentration of 0.43 pCi/g over an area of 170 square meters (203 square yards or 0.042 acres). Thirteen cubic meters represents about nine pick-up truck loads of sludge (at 50 cubic feet or 450 pounds per load).

Assuming an average sludge concentration of 250 pCi/g, 54 pick-up truck loads of sludge would raise the average Pu 239 concentration in a ¼ acre residential yard to less than 50 pCi/g. Using a more likely average sludge Pu 239 concentration of 25 pCi/g, more than 540 pick-up truck loads would be required to raise the average soil concentration to 5 pCi/g. A more reasonable volume of 5 pick-up truck loads of sludge at a concentration of 25 pCi/g would raise the average concentration of a ¼ acre yard to less than 0.05 pCi/g.

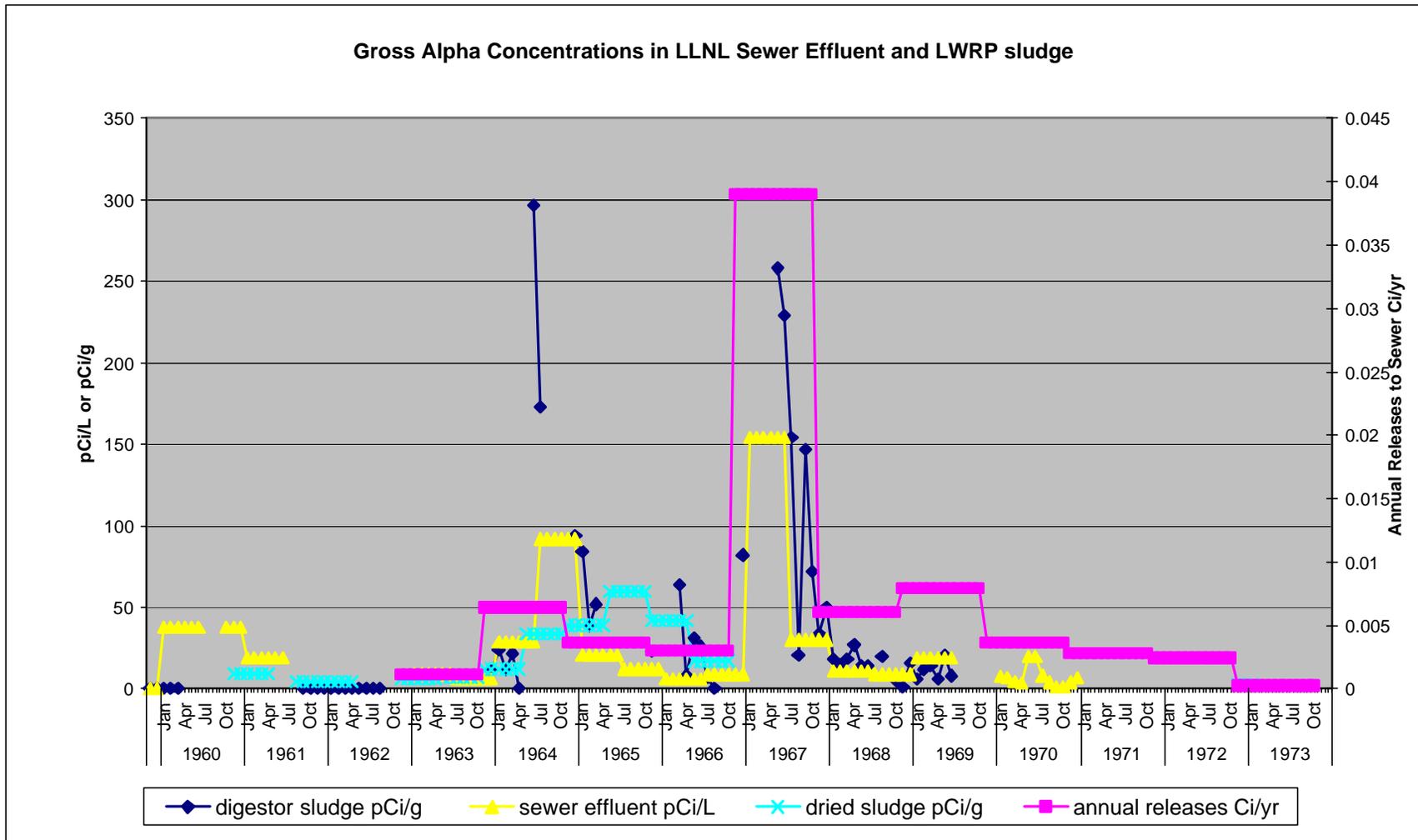


Figure 3. Gross alpha concentrations of digester sludge, effluent from LLNL, dried sludge from LWRP drying beds, and LLNL annual releases to sewer system. Sludge values are in pCi/g, sewer effluent values in pCi/L, and annual releases in Ci/year (right hand scale). Annual releases for 1973 are Pu 239 specific values; all others are gross alpha. Data underlying the chart are listed and the sources are referenced in Appendix 4. Note that the digester sludge values for June-64 through March-65, including the maximum observed value of 297 pCi/g, were analyzed as wet weight samples and cannot be compared with all other dry weight analyses.

Alternatively, if the sludge is not mixed with existing soil as an amendment, but is used as a cover material, it would take 108 pick up truck loads (50 cubic feet per load) to cover a 1/2 acre lot with 3 inches of sludge. The resulting sludge Pu 239 concentration would not be diluted by mixing, but would be at the average sludge concentration. Note that the above RESRAD dose estimates assume a 1/2 acre lot with uniform contamination to a depth of 2 meters (~7 feet). Each of the above sludge usage scenarios is unlikely, but possible. As there is no way to precisely estimate how much sludge may have been added to a garden or yard, the following dose evaluations will evaluate possible radiological doses from several possible concentrations of Pu 239 in sludge and residential soil. These concentrations include Pu 239 values measured in sludge and soil samples, and the maximum possible values derived from digester sludge gross alpha concentrations.

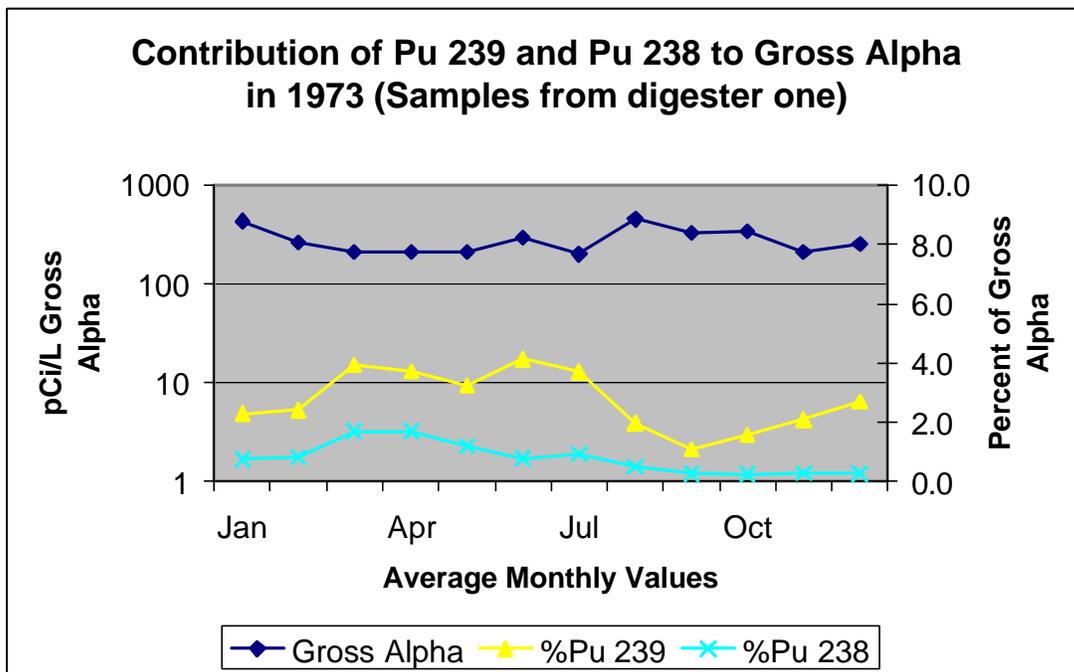


Figure 4. Relative contributions of Pu 239 and Pu 238 to gross alpha concentrations in monthly digester sludge samples for 1973. Data are from the 1973 annual environmental report (LLL 1973). Overall, the Pu 239 constitutes between 2% and 4% of the overall gross alpha concentration. The largest component of the gross alpha concentrations are probably uranium isotopes which were not specifically analyzed. The relative contribution of plutonium isotopes during this period represents baseline conditions. During a specific release episode, such as the May-June 1967 release, the relative plutonium contribution will be much higher while the baseline contribution of uranium and other radionuclides. Note that the gross alpha concentration and percent contribution are on different scales and that the concentration scale is logarithmic.

Section 4. Public Health Implications

One hundred millirem per year (mrem/yr; above background) is the effective dose limit established for the general population by the International Commission on Radiological Protection (ICRP 1991; from ATSDR 1999) and used by ATSDR as the minimal risk level (MRL; ATSDR 1999b). An MRL is defined as “An estimate of daily human exposure to a dose of radiation or chemical that is likely to be without appreciable risk of adverse non-cancerous⁸ effects over a specified period of time.” The US EPA suggests that levels of 15 mrem/year or less (EDE) are protective of human health. The CDHS, Radiological Health Branch uses a 25 mrem/year (EDE) as basis for comparison (CDHS 2002).

Figure 5 shows the average Pu 239 soil concentrations that would be required to produce annual doses of 15, 25, and 100 mrem/year. The soil concentrations are derived from the RESRAD model output and also may be derived from linear extrapolation of the 0.31 mrem/year dose from a soil concentration of 2.5 pCi/g. In order to produce an annual dose of 15 mrem/year (considered to be health protective by the US EPA; EPA 1997), a residential yard would have to have an **average** Pu 239 concentration of more than 122 pCi/g. Similarly, to produce an annual dose of 25 mrem/year (considered to be health protective by CDHS), a residential yard would have to have an **average** Pu 239 concentration of more than 204 pCi/g. A Pu 239 soil concentration of more than 816 pCi/g (average) would be required to produce an annual dose of 100 mrem/year (above background), which is considered health protective by the ATSDR and the ICRP.

These dose estimates and associated soil concentrations are derived using health protective assumptions for all exposure factors and durations. The estimated doses from these soil Pu 239 concentrations include ingestion of soil, inhalation of dust, ingestion of food grown in the soil, and direct external radiation. The intake rates and exposure durations for each of those routes of exposure are based on health-protective assumptions from the EPA exposure factor handbook or RESRAD default conditions as listed in the preceding section and Appendix 3.

Combining the above soil concentration-dose results with the LWRP gross alpha concentrations indicates that if the sludge was contaminated at a gross alpha concentration of 250 pCi/g, and that 108 truck loads of sludge were added to a 1/2 acre yard, the resulting dose would be less than the ATSDR MRL of 100 mrem/year. Although such an exposure scenario is possible, it is very unlikely. One or two truck loads of sludge at a concentration of 100 pCi/g, added to a yard would add a dose of 0.1 to 0.2 mrem/year to the natural background terrestrial dose of ~44 mrem/year (NCRP

⁸ Although the standard definition of an ATSDR MRL specifies only non-cancerous health effects, the MRL for ionizing radiation includes cancerous health effects (ATSDR 1999b). Also, although the ATSDR MRL is specific to external radiation, the ICRP effective dose limit does not specify either external or internal exposure and will be used as a screening level dose for the internal exposure evaluated in this study.

1987).⁹ Excess doses (above background) in the range of 0.1 to 0.2 mrem/year cannot be discriminated from natural background doses for the San Francisco area). The following sections will present a brief discussion of the toxicology of plutonium and the levels of radiation exposure that have been shown to produce cancer or other adverse health effects.

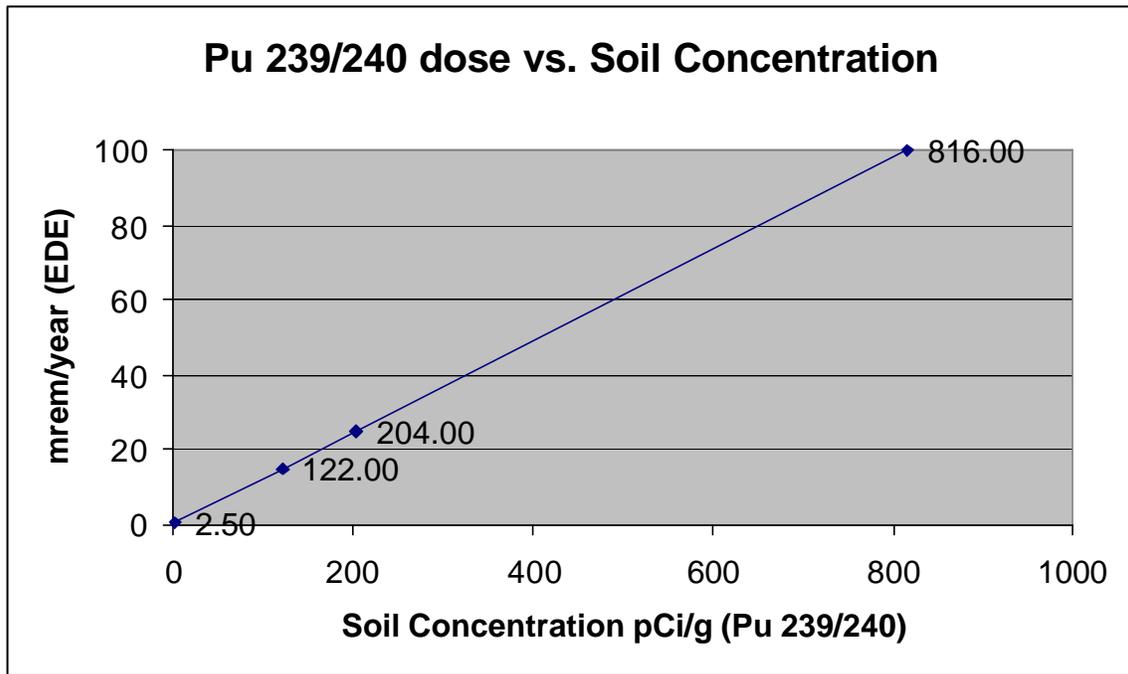


Figure 5. Pu 239 (and/or Pu 240) soil concentrations that produce annual radiological doses of 15, 25 and 100 mrem/year. Soil concentrations are derived from RESRAD soil guidance values for each dose and assume average concentrations over an entire area or residential yard. An average Pu 239 soil concentration of 122 pCi/g over an entire residential yard is required to produce an annual dose of 15 mrem/year. An average concentration of 204 pCi/g Pu 239 is required to produce an annual dose of 25 mrem/year, and an average concentration of 816 pCi/g will produce an annual dose of 100 mrem/year (above background).

⁹ The 95th percentile of external terrestrial background radiation doses for the San Francisco area is ~80 mrem/year (based on data from NCRP 1987).

Toxicology of Pu 239/240

Plutonium is a silvery-white radioactive metal that is a solid under normal conditions. Produced in a nuclear reactor by the conversion of uranium, plutonium is found in the environment as the result of fallout from atmospheric nuclear testing. The most common forms of plutonium (isotopes) are plutonium 238 and plutonium 239, abbreviated Pu 238 and Pu 239. Because plutonium is a radioactive element, it constantly undergoes changes called "radioactive decays." In this decay process, energy is released and a new radioactive product is formed. Most plutonium is found in nature combined with other substances, for example, plutonium dioxide (plutonium with oxygen) or plutonium nitrate (plutonium with nitrogen and oxygen) (ATSDR, 1990). As the contaminant of concern for the sewage sludge release is Pu 239, the remainder of this section will only deal with Pu 239. Pu 239 is an alpha emitter and a gamma emitter. The energy released by the radioactive decays may cause damage to cells or the surrounding tissues. In order for damage to occur, the radiation must either be absorbed by the surrounding cells or some of the energy as the radiation passes through the cell must be transferred to the cell and the surrounding medium (Johns and Cunningham, 1983).

Plutonium enters the body mainly through two pathways, inhalation and ingestion. Studies have shown that plutonium is not absorbed through the skin; however, it can enter the body via cuts and wounds (ATSDR, 1990). For all pathways, the Pu leaves the body mostly by feces and urine. Any plutonium that is not eliminated is absorbed by the body where it deposits in the organs. The most common organs for deposition following ingestion include the bone surfaces (skeleton) and liver. The lung, however, is the most impacted organ following inhalation (ICRP, 1989). As a result of these intakes, the plutonium generally stays in the body for decades and continues to expose the surrounding tissues to radiation.

The intake of plutonium may eventually increase your chance of developing cancer, but it would be several years before such cancer effects became apparent, especially at extremely low exposures. The experimental evidence is inconclusive, and studies of some human populations who have been exposed to low levels of plutonium have not definitely shown an increase in cancer. However, in laboratory animals, plutonium has been shown to cause both cancers and other damage, and might affect the ability to resist disease by reducing the immune response (ATSDR, 1990).

Plutonium is not easily absorbed into the body. The International Commission on Radiation Protection (ICRP) has reviewed the literature and recommends that an absorption coefficient of 0.5% (infants) or 0.05% (adults) be used for ingestion. In the case of inhalation, the ICRP recommends an absorption coefficient of 0.1% (infants) and 0.01% (adults) for plutonium with very low solubility in the lung. The absorption coefficient is the fractional uptake of a radionuclide that would be absorbed into blood without radiological decay. The low values of these coefficients mean that 99.9 to 99.5 of the plutonium ingested or inhaled is not absorbed by the body. Of the amount transferred to the blood, less than 25% would be transferred to the skeleton and another 25% or less would be transferred to the liver (ICRP, 1989). In other words, if one were to ingest a

picocurie of Pu 239, the amount that could be transferred to the skeleton or liver for possible deposition into the organs of interest is 0.00125 pCi for infants and 0.000125 pCi for adults. For an adult with a body weight of 70 kilograms (154 pounds), this is about 1.8×10^{-9} pCi/g body weight.

We do not know if plutonium deposited in the human body causes birth defects or affects the ability to have children. If plutonium can reach these sensitive target tissues, radioactivity from plutonium may produce these effects. A number of studies have documented levels of exposure that have caused no adverse health effects. Conversely, other studies have documented high levels of exposure that have caused adverse health effects. However, no information from peer-reviewed studies in humans or in animals has identified the specific level of exposure to plutonium in air, food, or water above which may result in harmful effects (ATSDR, 1990).

ATSDR also reported in its Toxicological Profile for Plutonium, a peer-reviewed analysis of the existing data, the following synopsis of the health effects of plutonium on humans (ATSDR 1990). Information on health effects in humans is very limited largely because exposed populations are small. Epidemiological studies of people who have been occupationally exposed by inhalation to plutonium have evaluated end points such as mortality, cancer, and systemic effects following chronic exposure. No information on health effects in humans after acute or intermediate exposure to plutonium was located. Nonetheless, the following observations were made in the toxicological profile:

1. No deaths in humans specifically associated with plutonium have been reported following acute plutonium exposure;
2. Neither deaths due to respiratory disease nor reduced respiratory function have been reported among the occupationally exposed cohorts;
3. No acute hematological effects were observed among human volunteers given a single injection of plutonium, but no follow-up study was conducted to assess the possibility of delayed effects;
4. Adverse hepatic effects associated with plutonium exposure have not been reported in humans;
5. Adverse musculoskeletal effects associated with plutonium exposure have not been reported in humans
6. Adverse gastrointestinal effects associated with plutonium exposure have not been reported in humans;
7. No reports exist showing an adverse immunological effects associated with plutonium exposure in humans;
8. With regards to genetic damage, epidemiological studies do not provide evidence that plutonium produces genetic damage in humans. In particular, the data from persons involved in the Manhattan project after a 30-year follow-up have been negative; and
9. In workers with long-term exposure to plutonium (including workers at Los Alamos National Laboratory, Rocky Flats Nuclear Weapons Plant, or Hanford Weapons Plant and the cohort involved in the original Manhattan project at

Los Alamos) no studies have demonstrated an unequivocal association between exposure to plutonium and cancer mortality 30 or more years after the exposures occurred.

Animal studies, however, have shown effects of plutonium exposure. For example, in dogs exposed to plutonium via inhalation, cancer and immunological effects were observed at a concentration of 1 pCi/g-animal weight (for an 8 kg dog, the dose would be 8,000 pCi). In mice, adverse health effects on the respiratory system were not observed following inhalation that resulted in a body burden of plutonium equivalent to 3 pCi/g-mouse weight. These exposures were over 2 weeks or less (ATSDR, 1990).

Rats given plutonium via ingestion over 2 weeks period had no adverse health effects with as much as 100 pCi/g body weight. The lowest observed effect level was approximately 300,000 pCi/g (ATSDR, 1990). These results indicate a significant difference in the dose effect from inhalation and ingestion. An inhaled dose is much more radiotoxic than an ingested dose. These factors are accounted for in the dose conversion factors and included in the RESRAD analysis (ANL, 2000).

Health effects associated with exposure to ionizing radiation

Exposure to radiation is expressed as two generic types, acute and chronic exposures. By definition, ATSDR considers acute exposures as exposures having a duration of less than 2 weeks; whereas, chronic exposures occur over a year or more (ATSDR, 1990, 1999).

The adverse health effects from acute exposures to radiation have been well defined as a result of the atomic bomb survivors, medical accidents and other medical accidents. The issues for this document are those health effects associated with chronic exposures to ionizing radiation. These health effects are more difficult to define, characterize, and discuss. ATSDR experience at sites contaminated with radioactive materials shows that chronic exposures are incremental in comparison to background. In the United States, background consists of naturally occurring radon (54%), terrestrial and cosmic radiation (8% each), and internal (11%). The remainder (19%) is associated with medical exposures and consumer products (ATSDR 1999). The typical average background radiation in the United States is 3.6 mSv (360 millirem) per year. Average external terrestrial (radionuclides in soil) background radiation exposures for the San Francisco area are about 44 mrem/year with a 95th percentile value of about 80 mrem/year (NCRP 1987).

Health Effects from background radiation

There have never been any peer-reviewed studies to show that background levels of radiation are harmful. In fact, there are portions of the globe where the background is higher than the typical area in the United States. According to the United Nations, the

background can vary from below 1 mSv (100 millirem) to above 6.4 mSv (640 millirem) per year or more. For example, for an area in China where elevated levels of natural background radiation are found, studies have shown a significant increase in chromosomal aberrations, but there have been no observed increases in adverse health effects (over the 20 or more years this area has been studied). Other areas in the world where there are high background radiation levels include India, Brazil, and Iran. The area in Iran, Ramsar, has verified doses as high as 130 mSv per year (13,000 millirem)¹⁰.

Incremental exposures above background radiation

Many studies have attempted to show a cause and effect from low-level chronic radiation exposure. In these studies, low dose has been defined as any dose less than 10 mSv (1,000 mrem). No studies exist for exposures or doses below this limit. For many of these low dose epidemiological studies, researchers used the standard mortality ratio (SMR) to estimate adverse health effects. The SMR is defined as the ratio of observed deaths in a population to the expected number of deaths as derived from rates in a standard population with adjustment of age and possibly other factors such as sex or race (Society for Risk Analysis). An SMR less than 1 indicates no causality or association.

An English study of over 95,000 radiation workers whose collective dose from external radiation is about 3200 man Sv ($3200/95000 = 34$ mSv or 3,400 mrem) only took into account external radiation exposure and dose. The results showed the standard mortality ratio for all cancers was less than 1 (Kendall et.al. 1992).

A later study by Cardis and coworkers included 95,000 nuclear industry workers in the United States, Canada, and the United Kingdom. The study participants were monitored for external radiation exposure (mostly gamma) and were employed for at least 6 months. In all, there were 15,825 deaths, of which 3976 were from cancer. The authors found no evidence of a dose response or mortality association from all causes or from all cancers. Of the cancer types, only leukemia (except for chronic lymphocytic and multiple myeloma) showed a significant association with cumulative external radiation dose (Cardis et.al. 1995). *From the cardis paper – “The combined analysis of the data for the workers demonstrated a significant ($P=0.046$) association between mortality from leukemia excluding CCL and radiation dose in a population receiving protracted low-dose-rate exposures.” They also state “The observed association between radiation dose and mortality from leukemia excluding CCL appeared to be restricted to myeloid leukemia, particularly CML”*

In a cohort study to determine if children were at risk of developing leukemia or other cancers before 25 years of age, Roman and coworkers included 39,557 children of male nuclear industry workers and 8883 of female workers. The study suggested that the

¹⁰ Several data sources were used in developing this section include internet searches and the Health Physics Journal and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports.

incidence of cancer and leukemia among children of nuclear industry employees is similar to that in the general population. The SMR for all cancers and leukemias for each sex of the worker was less than 1 (Roman et.al. 1999).

Special Consideration of Women and Children

The effect of radiation on humans, in general, has been well studied. However, there are few studies, especially with plutonium exposure, that are specific for women or children. In estimating radiological doses, the ICRP calculates dose conversion factors based on 6 age groups: 0 to 12 months; 1 to 2 years; 2 to 7 years; 7 to 12 years; 12 to 17 years; and more than 17 years in the cases of adult exposures. In some cases, such as the factors for plutonium, the adult exposures are calculated for 25 years or more (up to 70 years for this assessment) using the age-specific dose conversion factors. These factors also include time periods, body and organ weights, and intake rates that represent childhood exposures. Consequently, the dose assessment methodology, following the intake of radioactive materials by the general population, is representative of children and adults. Also an age-adjusted soil ingestion rate is used to account for childhood soil intake, which may be larger than adult intakes (EPA 1999). Food intake rates are based on the larger long-term adult rates which is health protective for children. Therefore, the ICRP methodology and the exposure factors used in this assessment are health protective for men, women, and children.

The Use of Dose for Public Health Assessments

The ATSDR uses radiation doses *instead of risk* in its public health documents for various reasons. Among these are the facts that dose coefficients are based on a more exact science; that is, the doses are based on physical constants and primary principles of physics such as energy absorption, and health effects resulting from radiation doses are based on a “weight-of-evidence” approach. Furthermore, the foundation of radiation health studies use *dose* because there is a long history of research in which health outcomes were evaluated on the radiation dose and not on the perceived risk. That is, the basis for health outcomes is direct observations using known parameters. ATSDR also recognizes there are uncertainties in these dose coefficients; however, the agency believes the magnitude of these uncertainties is less than the uncertainties associated with risk assessment methodologies.

ATSDR, in preparing its public health documents, also relies on site-specific parameters such as demographics, realistic land use, and other pertinent data related to the site. Using dose coefficients and modifying the coefficients for chemical forms and particle sizes, which is not typically done for risk assessments, allows for ATSDR to develop realistic values for the dose assessments as they pertain to public health documents.

The uncertainty in the dose effects lies within the middle ranges of exposure. Adverse health effects have been conclusively demonstrated for exposures greater than 10,000

mrem/year (ATSDR 1999). Numerous studies have also demonstrated that no adverse health effects have been documented for exposures of less than 360 mrem/year (ATSDR 1999). The ATSDR minimal risk level (MRL) for ionizing radiation (including Pu 239) is based on numerous evaluations of health effects from exposures to background and occupational levels of radiation. “The annual dose of 3.6 mSv per year (360 mrem/year) has not been associated with adverse health effects or increases in the incidence of cancers in humans or animals.” (ATSDR 1999). Consequently, 360 mrem/year is defined as a “No Observed Adverse Effect Level” (NOAEL). The derived MRL, which is further reduced by a factor of 3 to account for human variability (and conservatively rounded down from 120 mrem/year to 100 mrem/year) is protective of human health.

The science associated with risk is based on a model that, at low doses typically associated with small multiples of background, cannot be proven. ATSDR also realizes that every action, radiation dose, or activity has an associated risk. However, as no adverse health effects have been observed at levels considerably higher than 100 mrem/year (above background), there is no public health basis for using lower, risk-based screening values. A more complete discussion of the public health implications of dose vs. risk evaluations is presented in Appendix 5.

Adequacy of Available Data for Public Health Determination

The data underlying this public health assessment, as with all analytical data, have limitations involving sampling and measurement procedures. The most significant limitation is the lack of direct Pu 239 analyses of processed sludge following the 1964 and 1967 release events that may have been distributed to the Livermore community.¹¹ This limitation is resolved through the use of gross alpha data from both processed sludge and digester sludge. Available data indicate that gross alpha measurements will overestimate Pu 239 concentrations and that digester sludge concentrations will overestimate processed sludge concentrations. Consequently, use of digester sludge gross alpha concentrations is a health protective proxy for Pu 239 concentrations in processed sludge.

The use of the health protective gross alpha measurements presents another limitation. Because these values overestimate the processed sludge concentrations, they do not allow for direct evaluation of actual sludge concentrations. We only know that processed sludge Pu 239 concentrations are lower than the digester gross alpha values, we do not know how much lower. This limitation is not a problem as long as the Pu 239 doses calculated from the maximum, overestimated gross alpha concentrations are below levels of health concern. As the preceding sections indicate that the doses calculated from maximum gross alpha concentrations are below levels of health concern, this uncertainty

¹¹ Due to construction activities at LWRP during the 1965 to 1967 timeframe, it is unlikely that any sludge was distributed to the public (CDHS 2002). As a 1964 release to the sewer system would not show up in processed sludge until 1965, it is unlikely that any sludge from the 1964 release was distributed to the public.

in the available data does not present a significant problem in the use or evaluation of the available data.

Total reliance on the state-collected and analyzed digester gross alpha data set could also present several data limitations. There are several gaps in this data during the period 1960 to 1963, as well as after 1969 (Figure 3). However, during the period of those data gaps, sewer effluent and annual release data from LLNL are available. These data, which accurately track the CDHS digester gross alpha measurements during all other time periods, indicate that there were no significant Pu 239 (or gross alpha) releases during the time of the digester gross alpha data gaps.

Prior to May 1963, the state-collected digester gross alpha concentrations were reported as wet weight analyses (vs. dried weight analyses for all later time periods).¹² Although the difference in analytical methods may affect the absolute data values, the overall trends in the data indicate that the relative magnitudes are similar.

The 1964-65 time period includes the highest reported digester gross alpha concentration (297 pCi/g) as analyzed by CDPH. LLNL sewer effluent and annual release values during this same time period do indicate a release event(s), but not of the same magnitude as the May-June 1967 event. Processed sludge gross alpha concentrations for 1965 (~8-12 months following the digester gross alpha spike) reached 60 pCi/g (6 month average). These are the highest processed sludge gross alpha concentrations. Considering that digester sludge gross alpha concentrations for the 1964 and 1967 events were of similar magnitude (297 pCi/g vs. 258 pCi/g, respectively) suggests that processed sludge gross alpha concentrations following the 1967 release were also of a similar magnitude.

Community members have also expressed a concern that all of the data underlying this evaluation consist of gross alpha or Pu 239 concentrations averaged over different time periods. Digester concentrations are presented as monthly averages; processed sludge, LLNL sewer effluent, and annual release data are reported as 6 or 12 month average values¹³. The basis of this concern seems to be that the 6 or 12 month average values may miss short term events or spikes in the Pu 239 concentrations. This apparent limitation is resolved by the mixing or averaging that occurs in the sewage treatment process.

¹² The “Radiological Health News” of July 1964 contained the following statement: “A correction should be made in the data on sewage sludge. Beginning May 1963 all sewage sludge has been reported in picocuries per gram of dry sludge. Before that date it was reported in picocuries per gram of wet sludge. The footnote should be so corrected.” (Wong 2003).

¹³ During the period of concern in the 1960s, the LLNL monitoring data were collected and analyzed on a monthly basis. However, these data were only reported as 6 or 12 month average values. LLNL is currently re-examining the monthly data to ensure that the averaged values do not overlook any significant short-term events.

Figure 6 shows the gross alpha concentrations from daily samples collected and analyzed by LLNL. These data have recently been recalculated from historic monitoring data records (McConachie 2003) and monthly averages of the daily values are included in Appendix 4. Maxima of the daily samples are about 4 times greater than the monthly composite samples analyzed by CDPH (Figure 3; Appendix 4). However, due to the mixing and dilution that occurs during the treatment process, the resulting processed sludge will not have similar short term Pu 239 concentration peaks.

Sewage treatment and sludge production is an averaging process. Material is added to and pumped from the digesters with an approximate processing duration of 1 month (see Appendix 2; also confirmed by J. Dupont, former LWRP plant manager, personal communication with M. Evans, ATSDR, 2002). Sludge from the digesters is added to the lagoons or drying beds over periods of 1 to 5 years. Processed, dried sludge is milled or ground before distribution resulting in further mixing. Thus, the production of sludge represents a mixing or averaging process over a period of at least one to several years. The use of 6 or 12 month average concentrations to represent this processed sludge will not result in the loss of useful information. Because of the mixing inherent in the sewage treatment system, short term releases to the sewer system will not occur as short term spikes in the Pu 239 concentration of processed sludge.

The validity of all of the historical data has also been questioned because current quality control and data management practices were not utilized for the collection and analysis of historical monitoring data. There have been many improvements in the analytical and data management procedures underlying environmental monitoring programs from those of the 1960s. The direction of these improvements is the reliable and accurate determination of very low contaminant concentrations. This public health evaluation of Pu 239 or gross alpha concentrations is based on determination of the maximum concentrations. These maximum concentrations are well within the basic limitations of the historic gas flow proportional counting technique used to measure gross alpha concentrations.

The overall utility of the historical data is indicated by the convergent and similar trends of the different data types. The similar patterns of digester sludge, LLNL sewer effluent, dried sludge, and annual release data over time (Figure 3) show similar peaks and declines, albeit with some time lags. The time lags are a necessary artifact of the treatment process and the duration of the time lags are appropriate to the sewage processing timeframe. In other words, digester gross alpha concentrations go up when effluent concentrations from LLNL indicate they should go up. Gross alpha concentrations in processed sludge go up 8 to 12 months after digester concentrations go up.

There is some inherent uncertainty in all monitoring or sampling data. This is because the measurement of the contaminant concentration in a very small "sample" is assumed to represent the contaminant concentration of the entire volume or mass of media of concern. Some community members have expressed a desire for additional soil sampling throughout the Livermore community to determine the Pu 239 concentrations in any

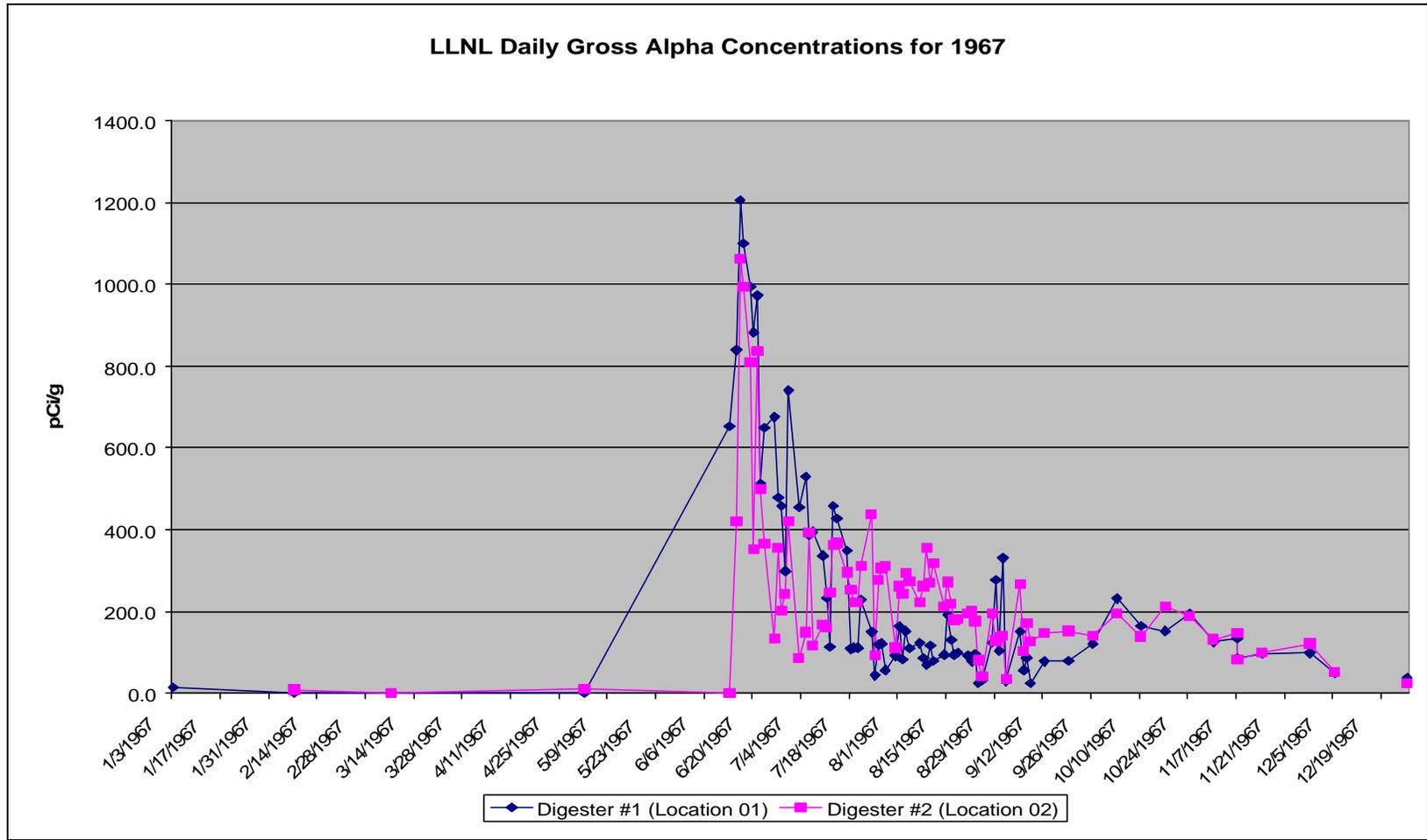


Figure 6. Daily measurements of gross alpha concentrations in LWRP digesters 1 and 2 in 1967 by LLNL (data from McConachie 2003). Note that the daily samples record higher concentrations than the monthly composites analyzed by CDPH (Figure 3).

areas where sludge from LWRP may have been distributed. Such sampling would be subject to the same types of uncertainty, with respect to sampling and analysis procedures, as past sampling. Further, the passage of more than 30 years following placement of any sludge from the 1967 release would make determination of sample locations highly uncertain and increase the amount of dilution with non-contaminated soils.

Exposure and Health Evaluation

The purpose of this PHA is to evaluate the public health implications of the historical distribution of Pu-contaminated sludge to the Livermore community by answering three specific questions: 1) What concentrations of Pu 239 in sludge would produce doses of public health concern? 2) Were the concentrations of Pu 239 in the sludge distributed to the public by LWRP greater than the levels of potential health concern? 3) Do the available data provide an adequate basis for this exposure assessment and the resulting public health conclusions? The ATSDR MRL or 100 mrem/year is used as a basis for determining radiological doses of public health concern. No adverse health effects have ever been documented from radiological doses of 100 mrem/year or less (above background).

With regard to question 1, a soil (100 percent sludge cover) Pu 239 concentration of 816 pCi/g (averaged over entire area) is required to produce a dose of 100 mrem/year, as calculated using RESRAD. This calculation includes health-protective exposure factors and includes ingestion of soil and garden crops, inhalation of dust, and external exposure. This calculation also assumes that the contaminated area covers an area of ½ acre to a depth of 1 meter, ½ of the area is unvegetated, and ½ of the resident's food is grown on the contaminated area. Considering that it would take 108 pick-up truck loads of sludge to cover a 1/2 acre lot (3 inch depth), such an exposure scenario, although possible, is very unlikely.

A nearly complete historical record of LWRP gross alpha concentrations for the period of 1960 through 1973 indicates that maximum digester sludge concentrations (as analyzed by CDPH) were less than 300 pCi/g. The digester sludge values show two distinct peaks corresponding with the 1964 and 1967 release episodes (297 pCi/g and 258 pCi/g, respectively). Gross alpha concentrations of LLNL effluent into the Livermore sewer system show the same peaks and provide supplementary data for those periods during which digester concentrations were not collected or analyzed. Collectively, the state analyzed digester sludge data and the LLNL analyzed effluent data indicate that the 1964 and 1967 release episodes represent the worst-case sludge concentrations.

As the concentrations of Pu 239 in processed sewage sludge following the 1964 episode of maximum digester sludge concentration were less than 816 pCi/g, it follows that the maximum Pu 239 concentrations in sludge were below levels of health concern. Although sludge concentrations following the 1967 event are not available, processed sludge gross alpha concentrations following the 297 pCi/g digester sludge values were

approximately 60 pCi/g. This indicates that digester sludge gross alpha concentrations are considerably reduced during the treatment process. As processed sludge is further milled and mixed before disposal, it is expected that processed sludge concentrations would have been additionally reduced before distribution to the public.

Several areas where contaminated sludge was placed have been sampled for Pu 239 concentrations. These areas include Big Trees Park, residential yards of LLNL employees, and a test garden on the LLNL facility. Maximum Pu 239 concentrations of these locations were less than 2 pCi/g. Although the initial sludge concentration of most of these areas is unknown, sludge and soil sampling at the LLNL test garden indicated that sludge Pu 239 concentrations are reduced by a factor of more than 5 in the resulting soil. This indicates that tilling and mixing of applied sludge will additionally reduce residential soil Pu 239 concentrations.

Assuming that the available gross alpha concentrations in LWRP sludge and LLNL sewer effluent are a reasonable substitute for direct Pu 239 measurements, the available data clearly indicate that the Pu 239-contaminated sludge does not result in radiological doses of public health concern. Monthly nuclide specific and gross alpha monitoring data for 1973 indicate that gross alpha concentrations overestimate Pu 239 concentrations. Consequently, the use of gross alpha concentrations as a proxy for Pu 239 concentrations is a health protective assumption.

No single data set is adequate for making the above public health determinations. There is not a consistent time series of processed sludge Pu 239 or gross alpha concentrations. Similarly, there are gaps in the digester sludge measurements, and the LLNL effluent data do not provide specific levels of sludge contamination. However, collectively, the available data do provide an adequate basis for the public health assessment. The trends in the different data values support and reinforce the individual data sets. As the different data sets supplement each other, gaps in any one data source do not present a critical lack of information. Additionally, the health protective assumptions used in calculating doses provide additional certainty for the health conclusions. Consequently, the available data provide an adequate basis for public health assessment.

The data evaluated in this public health assessment clearly indicate that, although Pu 239-contaminated sludge was distributed to the Livermore community, the resulting radiological doses were below levels of public health concern. Some community members have doubts about the adequacy of the available data as a basis for the public health determination. They have recommended the collection of additional information on the historic distribution of contaminated sludge and soil sampling of areas determined to have received such sludge. As there is no public health basis for such sampling and the proposed sample results would be inconclusive, ATSDR is not currently recommending additional soil sampling.

Section 5. Conclusions, Recommendations, and the Public Health Action Plan

Conclusions

Pu 239 (including coincidentally measured Pu 240) was historically released from LLNL to the Livermore sewer system as both low level chronic releases and as higher concentration short-term episodes. Release episodes of particular concern occurred in 1964 and 1967. The sewage effluent from LLNL is both monitored and regulated and available data indicates that the historical releases, including the 1964 and 1967 episodes did not exceed permitted release concentrations.

Processed sludge from the LWRP was historically distributed to the Livermore community for use as a soil amendment or additive. There has been considerable community concern that exposure to the Pu 239-contaminated sewage sludge could result in radiological doses of health concern. These community health concerns have been exacerbated by the lack of direct measurements of Pu 239 concentrations in the processed sludge and some uncertainty about the specific distribution of sludge following the 1964 and 1967 releases. Historical monitoring involved measurement of gross alpha concentrations rather than nuclide-specific Pu 239 measurements.

The following conclusions are based on our current knowledge of radiation health effects and the data reviewed and evaluated in this health assessment:

1. Pu 239 from LLNL was released to the Livermore sewer system and resulted in the contamination of LWRP sludge which may have been distributed to the Livermore community resulting in areas with Pu 239 soil concentrations above background.
2. Using health protective exposure assumptions, radiological doses from maximum measured concentrations of any distributed sludge are below levels of health concern. This evaluation assumes that digester sludge gross alpha concentrations represent Pu 239 concentrations and that digester sludge is spread uniformly over an entire residential yard. Pu 239 concentrations of processed sludge distributed to the Livermore community are calculated to be more than 10 times lower than digester sludge concentrations.
3. The available data and evaluations provide an adequate basis for these public health conclusions. Any additional sampling data will be subject to the same types of uncertainties as existing historical data.

Based on the above conclusions, the historic distribution of Pu-contaminated sewage sludge is determined to be no apparent public health hazard. This determination means that while exposure may have occurred, or may still be occurring, the resulting doses will not cause sickness or death.

Recommendations

As the potential maximum radiological doses from exposures to Pu 239-contaminated sludge are below levels of health concern, ATSDR has no recommendations concerning additional soil sampling in areas of known or unknown sludge distribution. However, because the community may still have unresolved community concerns about this issue, ATSDR offers the following recommendations:

1. Develop and present educational materials, based on the information included in this public health assessment, to the Livermore.
2. Continue current monitoring of Pu 239 (and other contaminant) concentrations in LLNL effluent and the LWRP sewage treatment system (as stipulated by existing discharge permit requirements).

Public Health Action Plan

1. ATSDR will prepare and distribute audience-specific educational materials based on the information presented in this PHA and other LLNL-specific ATSDR documents. ATSDR will conduct additional public availability sessions or make presentations at other community meetings to address community health concerns related to LLNL.
2. LLNL will continue current radiological monitoring, as stipulated in current discharge and operating permits, to ensure that future plutonium (and other radionuclide) releases are below levels of public health concern.

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Appendix 1: Glossary of Technical Terms

Absorption:	How a chemical enters a person's blood after the chemical has been swallowed, has come into contact with the skin, or has been breathed in.
Acute Exposure:	Contact with a chemical that happens once or only for a limited period of time. ATSDR defines acute exposures as those that might last up to 14 days.
Additive Effect:	A response to a chemical mixture, or combination of substances, that might be expected if the known effects of individual chemicals, seen at specific doses, were added together.
Adverse Health Effect:	A change in body function or the structures of cells that can lead to disease or health problems.
Antagonistic Effect:	A response to a mixture of chemicals or combination of substances that is less than might be expected if the known effects of individual chemicals, seen at specific doses, were added together.
ATSDR:	The A gency for T oxic S ubstances and D isease R egistry. ATSDR is a federal health agency in Atlanta, Georgia that deals with hazardous substance and waste site issues. ATSDR gives people information about harmful chemicals in their environment and tells people how to protect themselves from coming into contact with chemicals.
Background Level:	An average or expected amount of a chemical in a specific environment. Or, amounts of chemicals that occur naturally in a specific-environment.
Biota:	Used in public health, things that humans would eat – including animals, fish and plants.
Cancer:	A group of diseases which occur when cells in the body become abnormal and grow, or multiply, out of control.
Carcinogen:	Any substance shown to cause tumors or cancer in experimental studies.
CERCLA:	See C omprehensive E nvironmental R esponse, C ompensation, and L iability A ct.

Chronic Exposure: A contact with a substance or chemical that happens over a long period of time. ATSDR considers exposures of more than one year to be *chronic*.

Completed Exposure

Pathway: See **Exposure Pathway**.

**Comparison Value:
(CVs)**

Concentrations or the amount of substances in air, water, food, and soil that are unlikely, upon exposure, to cause adverse health effects. Comparison values are used by health assessors to select which substances and environmental media (air, water, food and soil) need additional evaluation while health concerns or effects are investigated.

**Comprehensive Environmental
Response, Compensation, and Liability**

Act (CERCLA): CERCLA was put into place in 1980. It is also known as **Superfund**. This act concerns releases of hazardous substances into the environment, and the cleanup of these substances and hazardous waste sites. ATSDR was created by this act and is responsible for looking into the health issues related to hazardous waste sites.

Concern: A belief or worry that chemicals in the environment might cause harm to people.

Concentration: How much or the amount of a substance present in a certain amount of soil, water, air, or food.

Contaminant: See **Environmental Contaminant**.

Curie (Ci): The quantity of radioactive material in which 37 billion transformations occur per second, which is approximately the activity of 1 gram of radium.

Delayed Health

Effect: A disease or injury that happens as a result of exposures that may have occurred far in the past.

Dermal Contact: A chemical getting onto your skin. (see **Route of Exposure**).

Dose: The amount of a substance to which a person may be exposed, usually on a daily basis. Dose is often explained as “amount of substance(s) per body weight per day”. For radioactive materials or radiation, *dose* denotes the quantity of radiation or energy

absorbed per unit body mass and is a generic term for absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose.

- Dose / Response:** The relationship between the amount of exposure (dose) and the change in body function or health that result.
- Duration:** The amount of time (days, months, years) that a person is exposed to a chemical.
- Effective Dose Equivalent:** The dose equivalent to organs and tissues of reference that will be received from an intake of radioactive material by an individual following the intake. Individual internal organ doses and the external dose are summed to determine the whole body dose.
- Environmental Contaminant:** A substance (chemical) that gets into a system (person, animal, or the environment) in amounts higher than that found in **Background Level**, or what would be expected.
- Environmental Media:** Usually refers to the air, water, and soil in which chemicals of interest are found. Sometimes refers to the plants and animals that are eaten by humans. **Environmental Media** is the second part of an **Exposure Pathway**.
- U.S. Environmental Protection Agency (EPA):** The federal agency that develops and enforces environmental laws to protect the environment and the public's health.
- Epidemiology:** The study of the different factors that determine how often, in how many people, and in which people will disease occur.
- Exposure:** Coming into contact with a chemical substance.(For the three ways people can come in contact with substances, see **Route of Exposure**.)
- Exposure Assessment:** The process of finding the ways people come in contact with chemicals, how often and how long they come in contact with chemicals, and the amounts of chemicals with which they come in contact.

Exposure Factors: Variables, such as frequency, duration, inhalation/ingestion rates that determine how much or how often a person is exposed to an environmental contaminant.

Exposure Pathway: A description of the way that a chemical moves from its source (where it began) to where and how people can come into contact with (or get exposed to) the chemical.

ATSDR defines an exposure pathway as having 5 parts:

1. Source of contamination,
2. Environmental Media and Transport Mechanism,
3. Point of Exposure,
4. Route of Exposure, and
5. Receptor Population.

When all 5 parts of an exposure pathway are present, it is called a **Completed Exposure Pathway**. Each of these 5 terms is defined in this Glossary.

Frequency: How often a person is exposed to a chemical over time; for example, every day, once a week, twice a month.

Gray: The international unit of absorbed radiation dose. One Gray (Gy) equals 100 rad.

Hazardous Waste: Substances that have been released or thrown away into the environment and, under certain conditions, could be harmful to people who come into contact with them.

Health Effect: ATSDR deals only with **Adverse Health Effects** (see definition in this Glossary).

Indeterminate Public

Health Hazard: The category is used in Public Health Assessment documents for sites where important information is lacking (missing or has not yet been gathered) about site-related chemical exposures.

Ingestion: Swallowing something, as in eating or drinking. It is a way a chemical can enter your body (See **Route of Exposure**).

Inhalation: Breathing. It is a way a chemical can enter your body (See **Route of Exposure**).

LOAEL: **Lowest Observed Adverse Effect Level.** The lowest dose of a chemical in a study, or group of studies, that has caused harmful health effects in people or animals.

- Malignancy:** See **Cancer**.
- MRL:** **Minimal Risk Level.** An estimate of daily human exposure – by a specified route and length of time -- to a dose of chemical that is likely to be without a measurable risk of adverse, noncancerous effects. An MRL should not be used as a predictor of adverse health effects.
- NPL:** The **National Priorities List.** (Which is part of **Superfund**.) A list kept by the U.S. Environmental Protection Agency (EPA) of the most serious, uncontrolled or abandoned hazardous waste sites in the country. An NPL site needs to be cleaned up or is being looked at to see if people can be exposed to chemicals from the site.
- NOAEL:** **No Observed Adverse Effect Level.** The highest dose of a chemical in a study, or group of studies, that did not cause harmful health effects in people or animals.
- No Apparent Public Health Hazard:** The category is used in ATSDR's Public Health Assessment documents for sites where exposure to site-related chemicals may have occurred in the past or is still occurring but the exposures are not at levels expected to cause adverse health effects.
- No Public Health Hazard:** The category is used in ATSDR's Public Health Assessment documents for sites where there is evidence of an absence of exposure to site-related chemicals.
- PHA:** **Public Health Assessment.** A report or document that looks at chemicals at a hazardous waste site and tells if people could be harmed from coming into contact with those chemicals. The PHA also tells if possible further public health actions are needed.
- Point of Exposure:** The place where someone can come into contact with a contaminated environmental medium (air, water, food or soil). For examples: the area of a playground that has contaminated dirt, a contaminated spring used for drinking water, the location where fruits or vegetables are grown in contaminated soil, or the backyard area where someone might breathe contaminated air.
- Population:** A group of people in a certain area; or the number of people in a that have similar exposure factors.

**Public Health
Assessment(s):**

See **PHA**.

**Public Health
Hazard:**

The category is used in PHAs for sites that have certain physical features or evidence of chronic, site-related chemical exposure that could result in adverse health effects.

**Public Health
Hazard Criteria:**

PHA categories given to a site which tell whether people could be harmed by conditions present at the site. Each are defined in the Glossary. The categories are:

- S Urgent Public Health Hazard
- S Public Health Hazard
- S Indeterminate Public Health Hazard
- S No Apparent Public Health Hazard
- S No Public Health Hazard

Rad:

The special unit of absorbed dose. One rad is equal to an absorbed dose of 0.01 Gray.

**Receptor
Population:**

People who live or work in the path of one or more chemicals, and who could come into contact with them (See **Exposure Pathway**).

**Reference Dose
(RfD):**

An estimate, with safety factors (see **safety factor**) built in, of the daily, life-time exposure of human populations to a possible hazard that is not likely to cause harm to the person.

Rem:

A unit of radiation dose equivalent. The dose equivalent in rem is numerically equal to the absorbed dose in rad multiplied by a quality factor. A mrem is 1e-3 Rem.

Route of Exposure:

The way a chemical can get into a person's body. There are three exposure routes:

- breathing (also called inhalation),
- eating or drinking (also called ingestion), and
- or getting something on the skin (also called dermal contact).

Safety Factor:

Also called **Uncertainty Factor**. When scientists don't have enough information to decide if an exposure will cause harm to people, they use "safety factors" and formulas in place of the information that is not known. These factors and formulas can

help determine the amount of a chemical that is not likely to cause harm to people.

Sample: A small number of items or people chosen from a larger population that is used to characterize the entire population (See **Population**).

Sievert: The SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts equals the absorbed dose in gray multiplied by the quality factor (1 Sv = 100 rem; 1 microsievert = 1E-06 sieverts).

Source (of Contamination): The place where a chemical comes from, such as a landfill, pond, creek, incinerator, tank, or drum. Contaminant source is the first part of an **Exposure Pathway**.

Special Populations: People who may be more sensitive to chemical exposures because of certain factors such as age, a disease they already have, occupation, sex, or certain behaviors (like cigarette smoking). Children, pregnant women, and older people are often considered special populations.

Statistics: A branch of the math process of collecting, looking at, and summarizing data or information.

Survey: A way to collect information or data from a group of people (**population**). Surveys can be done by phone, mail, or in person. ATSDR cannot do surveys of more than nine people without approval from the U.S. Department of Health and Human Services.

Synergistic effect: A health effect from an exposure to more than one chemical, where one of the chemicals worsens the effect of another chemical. The combined effect of the chemicals acting together are greater than the effects of the chemicals acting by themselves.

Toxic: Harmful. Any substance or chemical can be toxic at a certain dose (amount). The dose is what determines the potential harm of a chemical and whether it would cause someone to get sick.

Toxicology: The study of the harmful effects of chemicals on humans or animals.

Tumor: Abnormal growth of tissue or cells that have formed a lump or mass.

Uncertainty Factor: See **Safety Factor**.

**Urgent Public
Health Hazard:**

This category is used in ATSDR's Public Health Assessment documents for sites that have certain physical features or evidence of short-term (less than 1 year), site-related chemical exposure that could result in adverse health effects and require quick intervention to stop people from being exposed.

Appendix 2: 1967 Assessment of Pu 239 Release

Letter and Attachment concerning “Summary Hazards Analysis- PU-AM Release to Sanitary Sewer” from D.C. Sewell, Associate Director, LRL, to E.C. Shute, Manager, San Francisco Operations Office, U.S. Atomic Energy Commission, August 22, 1967.

B-1 ³ Pa-231 3
 8.500E-01 ³ 1.280E+00 ³ DCF2(2) 3
 B-1 ³ Pu-239 3
 1.860E-01 ³ 4.290E-01 ³ DCF2(3) 3
 B-1 ³ Pu-240 3
 1.860E-01 ³ 4.290E-01 ³ DCF2(4) 3
 B-1 ³ Ra-228+D 3
 5.080E-03 ³ 5.080E-03 ³ DCF2(5) 3
 B-1 ³ Th-228+D 3
 3.450E-01 ³ 3.450E-01 ³ DCF2(6) 3
 B-1 ³ Th-232 3
 1.640E+00 ³ 1.640E+00 ³ DCF2(7) 3
 B-1 ³ U-235+D 3
 3.130E-02 ³ 1.230E-01 ³ DCF2(8) 3
 B-1 ³ U-236 3
 1.250E-01 ³ 1.250E-01 ³ DCF2(9) 3
 3 3
 3 3
 D-1 ³ Dose conversion factors for ingestion, mrem/pCi: 3
 3 3
 D-1 ³ Ac-227+D 3
 1.190E-03 ³ 1.480E-02 ³ DCF3(1) 3
 D-1 ³ Pa-231 3
 1.770E-03 ³ 1.060E-02 ³ DCF3(2) 3
 D-1 ³ Pu-239 3
 9.280E-04 ³ 3.540E-03 ³ DCF3(3) 3
 D-1 ³ Pu-240 3
 9.280E-04 ³ 3.540E-03 ³ DCF3(4) 3
 D-1 ³ Ra-228+D 3
 1.440E-03 ³ 1.440E-03 ³ DCF3(5) 3
 D-1 ³ Th-228+D 3
 8.080E-04 ³ 8.080E-04 ³ DCF3(6) 3
 D-1 ³ Th-232 3
 2.730E-03 ³ 2.730E-03 ³ DCF3(7) 3
 D-1 ³ U-235+D 3
 1.730E-04 ³ 2.670E-04 ³ DCF3(8) 3
 D-1 ³ U-236 3
 2.690E-04 ³ 2.690E-04 ³ DCF3(9) 3
 3 3
 3 3
 D-34 ³ Food transfer factors: 3
 3 3
 D-34 ³ Ac-227+D , plant/soil concentration ratio, dimensionless 3
 2.500E-03 ³ 2.500E-03 ³ RTF(1,1) 3
 D-34 ³ Ac-227+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) 3
 2.000E-05 ³ 2.000E-05 ³ RTF(1,2) 3
 D-34 ³ Ac-227+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d) 3
 2.000E-05 ³ 2.000E-05 ³ RTF(1,3) 3
 D-34 ³ 3 3
 3 3
 D-34 ³ Pa-231 , plant/soil concentration ratio, dimensionless 3
 1.000E-02 ³ 1.000E-02 ³ RTF(2,1) 3
 D-34 ³ Pa-231 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) 3
 5.000E-03 ³ 5.000E-03 ³ RTF(2,2) 3
 D-34 ³ Pa-231 , milk/livestock-intake ratio, (pCi/L)/(pCi/d) 3
 5.000E-06 ³ 5.000E-06 ³ RTF(2,3) 3

D-34 ³ U-235+D , plant/soil concentration ratio, dimensionless ³
2.500E-03 ³ 2.500E-03 ³ RTF(8,1)
D-34 ³ U-235+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) ³
3.400E-04 ³ 3.400E-04 ³ RTF(8,2)
D-34 ³ U-235+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d) ³
6.000E-04 ³ 6.000E-04 ³ RTF(8,3)
D-34 ³ ³
D-34 ³ U-236 , plant/soil concentration ratio, dimensionless ³
2.500E-03 ³ 2.500E-03 ³ RTF(9,1)
D-34 ³ U-236 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d) ³
3.400E-04 ³ 3.400E-04 ³ RTF(9,2)
D-34 ³ U-236 , milk/livestock-intake ratio, (pCi/L)/(pCi/d) ³
6.000E-04 ³ 6.000E-04 ³ RTF(9,3)
³ ³
D-5 ³ Bioaccumulation factors, fresh water, L/kg: ³
³ ³
D-5 ³ Ac-227+D , fish ³
1.500E+01 ³ 1.500E+01 ³ BIOFAC(1,1)
D-5 ³ Ac-227+D , crustacea and mollusks ³
1.000E+03 ³ 1.000E+03 ³ BIOFAC(1,2)
D-5 ³ ³
D-5 ³ Pa-231 , fish ³
1.000E+01 ³ 1.000E+01 ³ BIOFAC(2,1)
D-5 ³ Pa-231 , crustacea and mollusks ³
1.100E+02 ³ 1.100E+02 ³ BIOFAC(2,2)
D-5 ³ ³
D-5 ³ Pu-239 , fish ³
3.000E+01 ³ 3.000E+01 ³ BIOFAC(3,1)
D-5 ³ Pu-239 , crustacea and mollusks ³
1.000E+02 ³ 1.000E+02 ³ BIOFAC(3,2)
D-5 ³ ³
D-5 ³ Pu-240 , fish ³
3.000E+01 ³ 3.000E+01 ³ BIOFAC(4,1)
D-5 ³ Pu-240 , crustacea and mollusks ³
1.000E+02 ³ 1.000E+02 ³ BIOFAC(4,2)
D-5 ³ ³
D-5 ³ Ra-228+D , fish ³
5.000E+01 ³ 5.000E+01 ³ BIOFAC(5,1)
D-5 ³ Ra-228+D , crustacea and mollusks ³
2.500E+02 ³ 2.500E+02 ³ BIOFAC(5,2)
D-5 ³ ³
D-5 ³ Th-228+D , fish ³
1.000E+02 ³ 1.000E+02 ³ BIOFAC(6,1)
D-5 ³ Th-228+D , crustacea and mollusks ³
5.000E+02 ³ 5.000E+02 ³ BIOFAC(6,2)
D-5 ³ ³
D-5 ³ Th-232 , fish ³
1.000E+02 ³ 1.000E+02 ³ BIOFAC(7,1)

R011	3	Times for calculations (yr)		3	not used	3
0.000E+00	3	---	3	T(9)		
R011	3	Times for calculations (yr)		3	not used	3
0.000E+00	3	---	3	T(10)		
	3					3
	3					3
R012	3	Initial principal radionuclide (pCi/g): Pu-239		3	2.040E+00	3
0.000E+00	3	---	3	S1(3)		
R012	3	Initial principal radionuclide (pCi/g): Pu-240		3	4.600E-01	3
0.000E+00	3	---	3	S1(4)		
R012	3	Concentration in groundwater (pCi/L): Pu-239		3	not used	3
0.000E+00	3	---	3	W1(3)		
R012	3	Concentration in groundwater (pCi/L): Pu-240		3	not used	3
0.000E+00	3	---	3	W1(4)		
	3					3
	3					3
R013	3	Cover depth (m)		3	0.000E+00	3
0.000E+00	3	---	3	COVER0		
R013	3	Density of cover material (g/cm**3)		3	not used	3
1.500E+00	3	---	3	DENSCV		
R013	3	Cover depth erosion rate (m/yr)		3	not used	3
1.000E-03	3	---	3	VCV		
R013	3	Density of contaminated zone (g/cm**3)		3	1.500E+00	3
1.500E+00	3	---	3	DENSCZ		
R013	3	Contaminated zone erosion rate (m/yr)		3	1.000E-03	3
1.000E-03	3	---	3	VCZ		
R013	3	Contaminated zone total porosity		3	4.000E-01	3
4.000E-01	3	---	3	TPCZ		
R013	3	Contaminated zone field capacity		3	2.000E-01	3
2.000E-01	3	---	3	FCCZ		
R013	3	Contaminated zone hydraulic conductivity (m/yr)		3	1.000E+01	3
1.000E+01	3	---	3	HCCZ		
R013	3	Contaminated zone b parameter		3	5.300E+00	3
5.300E+00	3	---	3	BCZ		
R013	3	Average annual wind speed (m/sec)		3	3.890E+00	3
2.000E+00	3	---	3	WIND		
R013	3	Humidity in air (g/m**3)		3	not used	3
8.000E+00	3	---	3	HUMID		
R013	3	Evapotranspiration coefficient		3	5.000E-01	3
5.000E-01	3	---	3	EVAPTR		
R013	3	Precipitation (m/yr)		3	3.000E-01	3
1.000E+00	3	---	3	PRECIP		
R013	3	Irrigation (m/yr)		3	2.000E-01	3
2.000E-01	3	---	3	RI		
R013	3	Irrigation mode		3	overhead	3
overhead	3	---	3	IDITCH		
R013	3	Runoff coefficient		3	2.000E-01	3
2.000E-01	3	---	3	RUNOFF		
R013	3	Watershed area for nearby stream or pond (m**2)		3	1.000E+06	3
1.000E+06	3	---	3	WAREA		
R013	3	Accuracy for water/soil computations		3	1.000E-03	3
1.000E-03	3	---	3	EPS		
	3					3
	3					3
R014	3	Density of saturated zone (g/cm**3)		3	1.500E+00	3
1.500E+00	3	---	3	DENSAQ		

```

R014 3 Saturated zone total porosity          3 4.000E-01 3
4.000E-01 3 --- 3 TPSZ
R014 3 Saturated zone effective porosity      3 2.000E-01 3
2.000E-01 3 --- 3 EPSZ
R014 3 Saturated zone field capacity          3 2.000E-01 3
2.000E-01 3 --- 3 FCSZ
R014 3 Saturated zone hydraulic conductivity (m/yr) 3 1.000E+02 3
1.000E+02 3 --- 3 HCSZ
R014 3 Saturated zone hydraulic gradient      3 2.000E-02 3
2.000E-02 3 --- 3 HGWT
R014 3 Saturated zone b parameter            3 5.300E+00 3
5.300E+00 3 --- 3 BSZ
R014 3 Water table drop rate (m/yr)          3 1.000E-03 3
1.000E-03 3 --- 3 VWT
R014 3 Well pump intake depth (m below water table) 3 1.000E+01 3
1.000E+01 3 --- 3 DWIBWT
R014 3 Model: Nondispersion (ND) or Mass-Balance (MB) 3 ND 3
ND 3 --- 3 MODEL
R014 3 Well pumping rate (m**3/yr)           3 2.500E+02 3
2.500E+02 3 --- 3 UW

```

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Summary : Residential Scenario: Sludge; half acre contaminated zone;
EPA exposure factors
File : residential epa half acre.RAD

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Site-Specific Parameter

Summary (continued)

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0 3 User 3
3 Used by RESRAD 3 Parameter
Menu 3 Parameter 3 Input 3
Default 3 (If different from user input) 3 Name

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AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA

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R015 3 Number of unsaturated zone strata      3 1 3
1 3 --- 3 NS
R015 3 Unsat. zone 1, thickness (m)          3 4.000E+00 3
4.000E+00 3 --- 3 H(1)
R015 3 Unsat. zone 1, soil density (g/cm**3) 3 1.500E+00 3
1.500E+00 3 --- 3 DENSUZ(1)
R015 3 Unsat. zone 1, total porosity        3 4.000E-01 3
4.000E-01 3 --- 3 TPUZ(1)
R015 3 Unsat. zone 1, effective porosity    3 2.000E-01 3
2.000E-01 3 --- 3 EPUZ(1)
R015 3 Unsat. zone 1, field capacity        3 2.000E-01 3
2.000E-01 3 --- 3 FCUZ(1)
R015 3 Unsat. zone 1, soil-specific b parameter 3 5.300E+00 3
5.300E+00 3 --- 3 BUZ(1)
R015 3 Unsat. zone 1, hydraulic conductivity (m/yr) 3 1.000E+01 3
1.000E+01 3 --- 3 HCUZ(1)
3 3
3 3
R016 3 Distribution coefficients for Pu-239 3 3
3 3
R016 3 Contaminated zone (cm**3/g)          3 2.000E+03 3
2.000E+03 3 --- 3 DCNUCC( 3)

```

R016	3	Unsaturated zone 1 (cm**3/g)		3	2.000E+03	3
2.000E+03	3	---	3	DCNUCU(3,1)		
R016	3	Saturated zone (cm**3/g)		3	2.000E+03	3
2.000E+03	3	---	3	DCNUCS(3)		
R016	3	Leach rate (/yr)		3	0.000E+00	3
0.000E+00	3	3.666E-05	3	ALEACH(3)		
R016	3	Solubility constant		3	0.000E+00	3
0.000E+00	3	not used	3	SOLUBK(3)		
	3					3
	3					3
R016	3	Distribution coefficients for Pu-240		3		3
	3					3
R016	3	Contaminated zone (cm**3/g)		3	2.000E+03	3
2.000E+03	3	---	3	DCNUCC(4)		
R016	3	Unsaturated zone 1 (cm**3/g)		3	2.000E+03	3
2.000E+03	3	---	3	DCNUCU(4,1)		
R016	3	Saturated zone (cm**3/g)		3	2.000E+03	3
2.000E+03	3	---	3	DCNUCS(4)		
R016	3	Leach rate (/yr)		3	0.000E+00	3
0.000E+00	3	3.666E-05	3	ALEACH(4)		
R016	3	Solubility constant		3	0.000E+00	3
0.000E+00	3	not used	3	SOLUBK(4)		
	3					3
	3					3
R016	3	Distribution coefficients for daughter Ac-227		3		3
	3					3
R016	3	Contaminated zone (cm**3/g)		3	2.000E+01	3
2.000E+01	3	---	3	DCNUCC(1)		
R016	3	Unsaturated zone 1 (cm**3/g)		3	2.000E+01	3
2.000E+01	3	---	3	DCNUCU(1,1)		
R016	3	Saturated zone (cm**3/g)		3	2.000E+01	3
2.000E+01	3	---	3	DCNUCS(1)		
R016	3	Leach rate (/yr)		3	0.000E+00	3
0.000E+00	3	3.630E-03	3	ALEACH(1)		
R016	3	Solubility constant		3	0.000E+00	3
0.000E+00	3	not used	3	SOLUBK(1)		
	3					3
	3					3
R016	3	Distribution coefficients for daughter Pa-231		3		3
	3					3
R016	3	Contaminated zone (cm**3/g)		3	5.000E+01	3
5.000E+01	3	---	3	DCNUCC(2)		
R016	3	Unsaturated zone 1 (cm**3/g)		3	5.000E+01	3
5.000E+01	3	---	3	DCNUCU(2,1)		
R016	3	Saturated zone (cm**3/g)		3	5.000E+01	3
5.000E+01	3	---	3	DCNUCS(2)		
R016	3	Leach rate (/yr)		3	0.000E+00	3
0.000E+00	3	1.461E-03	3	ALEACH(2)		
R016	3	Solubility constant		3	0.000E+00	3
0.000E+00	3	not used	3	SOLUBK(2)		
	3					3
	3					3
R016	3	Distribution coefficients for daughter Ra-228		3		3
	3					3
R016	3	Contaminated zone (cm**3/g)		3	7.000E+01	3
7.000E+01	3	---	3	DCNUCC(5)		

R016 3 Unsaturated zone 1 (cm**3/g) 3 7.000E+01 3
7.000E+01 3 --- 3 DCNUCU(5,1)
R016 3 Saturated zone (cm**3/g) 3 7.000E+01 3
7.000E+01 3 --- 3 DCNUCS(5)
R016 3 Leach rate (/yr) 3 0.000E+00 3
0.000E+00 3 1.045E-03 3 ALEACH(5)
R016 3 Solubility constant 3 0.000E+00 3
0.000E+00 3 not used 3 SOLUBK(5)
3 3

3 3
R016 3 Distribution coefficients for daughter Th-228 3 3
3 3

R016 3 Contaminated zone (cm**3/g) 3 6.000E+04 3
6.000E+04 3 --- 3 DCNUCC(6)
R016 3 Unsaturated zone 1 (cm**3/g) 3 6.000E+04 3
6.000E+04 3 --- 3 DCNUCU(6,1)
R016 3 Saturated zone (cm**3/g) 3 6.000E+04 3
6.000E+04 3 --- 3 DCNUCS(6)
R016 3 Leach rate (/yr) 3 0.000E+00 3
0.000E+00 3 1.222E-06 3 ALEACH(6)
R016 3 Solubility constant 3 0.000E+00 3
0.000E+00 3 not used 3 SOLUBK(6)

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Summary : Residential Scenario: Sludge; half acre contaminated zone;
EPA exposure factors
File : residential epa half acre.RAD

Site-Specific Parameter

Summary (continued)

0	3	3	User	3
3	Used by RESRAD	3	Parameter	3
Menu	3	Parameter	3	Input
Default	3	(If different from user input)	3	Name

AA
AA

R016 3 Distribution coefficients for daughter Th-232 3 3
3 3
R016 3 Contaminated zone (cm**3/g) 3 6.000E+04 3
6.000E+04 3 --- 3 DCNUCC(7)
R016 3 Unsaturated zone1 (cm**3/g) 3 6.000E+04 3
6.000E+04 3 --- 3 DCNUCU(7,1)
R016 3 Saturated zone (cm**3/g) 3 6.000E+04 3
6.000E+04 3 --- 3 DCNUCS(7)
R016 3 Leach rate (/yr) 3 0.000E+00 3
0.000E+00 3 1.222E-06 3 ALEACH(7)
R016 3 Solubility constant 3 0.000E+00 3
0.000E+00 3 not used 3 SOLUBK(7)
3 3

3 3
R016 3 Distribution coefficients for daughter U-235 3 3
3 3
R016 3 Contaminated zone (cm**3/g) 3 5.000E+01 3
5.000E+01 3 --- 3 DCNUCC(8)
R016 3 Unsaturated zone 1 (cm**3/g) 3 5.000E+01 3
5.000E+01 3 --- 3 DCNUCU(8,1)

R016	3	Saturated zone (cm**3/g)		3	5.000E+01	3
5.000E+01	3	---	3	DCNUCS(8)		
R016	3	Leach rate (/yr)		3	0.000E+00	3
0.000E+00	3	1.461E-03	3	ALEACH(8)		
R016	3	Solubility constant		3	0.000E+00	3
0.000E+00	3	not used	3	SOLUBK(8)		
	3					3
	3					3
R016	3	Distribution coefficients for daughter U-236		3		3
	3					
R016	3	Contaminated zone (cm**3/g)		3	5.000E+01	3
5.000E+01	3	---	3	DCNUCC(9)		
R016	3	Unsaturated zone 1 (cm**3/g)		3	5.000E+01	3
5.000E+01	3	---	3	DCNUCU(9,1)		
R016	3	Saturated zone (cm**3/g)		3	5.000E+01	3
5.000E+01	3	---	3	DCNUCS(9)		
R016	3	Leach rate (/yr)		3	0.000E+00	3
0.000E+00	3	1.461E-03	3	ALEACH(9)		
R016	3	Solubility constant		3	0.000E+00	3
0.000E+00	3	not used	3	SOLUBK(9)		
	3					3
	3					3
R017	3	Inhalation rate (m**3/yr)		3	8.400E+03	3
8.400E+03	3	---	3	INHALR		
R017	3	Mass loading for inhalation (g/m**3)		3	1.000E-04	3
1.000E-04	3	---	3	MLINH		
R017	3	Exposure duration		3	3.000E+01	3
3.000E+01	3	---	3	ED		
R017	3	Shielding factor, inhalation		3	4.000E-01	3
4.000E-01	3	---	3	SHF3		
R017	3	Shielding factor, external gamma		3	7.000E-01	3
7.000E-01	3	---	3	SHF1		
R017	3	Fraction of time spent indoors		3	6.830E-01	3
5.000E-01	3	---	3	FIND		
R017	3	Fraction of time spent outdoors (on site)		3	3.170E-01	3
2.500E-01	3	---	3	FOTD		
R017	3	Shape factor flag, external gamma		3	-1.000E+00	3
1.000E+00	3	-1 shows non-circular AREA.	3	FS		
R017	3	Radii of shape factor array (used if FS = -1):		3		3
	3					
R017	3	Outer annular radius (m), ring 1:		3	5.000E+01	3
5.000E+01	3	---	3	RAD_SHAPE(1)		
R017	3	Outer annular radius (m), ring 2:		3	7.071E+01	3
7.071E+01	3	---	3	RAD_SHAPE(2)		
R017	3	Outer annular radius (m), ring 3:		3	0.000E+00	3
0.000E+00	3	---	3	RAD_SHAPE(3)		
R017	3	Outer annular radius (m), ring 4:		3	0.000E+00	3
0.000E+00	3	---	3	RAD_SHAPE(4)		
R017	3	Outer annular radius (m), ring 5:		3	0.000E+00	3
0.000E+00	3	---	3	RAD_SHAPE(5)		
R017	3	Outer annular radius (m), ring 6:		3	0.000E+00	3
0.000E+00	3	---	3	RAD_SHAPE(6)		
R017	3	Outer annular radius (m), ring 7:		3	0.000E+00	3
0.000E+00	3	---	3	RAD_SHAPE(7)		
R017	3	Outer annular radius (m), ring 8:		3	0.000E+00	3
0.000E+00	3	---	3	RAD_SHAPE(8)		

```

R017 3 Outer annular radius (m), ring 9: 3 0.000E+00 3
0.000E+00 3 --- 3 RAD_SHAPE( 9)
R017 3 Outer annular radius (m), ring 10: 3 0.000E+00 3
0.000E+00 3 --- 3 RAD_SHAPE(10)
R017 3 Outer annular radius (m), ring 11: 3 0.000E+00 3
0.000E+00 3 --- 3 RAD_SHAPE(11)
R017 3 Outer annular radius (m), ring 12: 3 0.000E+00 3
0.000E+00 3 --- 3 RAD_SHAPE(12)
3 3

```

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```

Summary : Residential Scenario: Sludge; half acre contaminated zone;
EPA exposure factors
File : residential epa half acre.RAD

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Site-Specific Parameter

Summary (continued)

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0 3 User 3
3 Used by RESRAD 3 Parameter
Menu 3 Parameter 3 Input 3
Default 3 (If different from user input) 3 Name

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AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA

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R017 3 Fractions of annular areas within AREA: 3 3
3 3
R017 3 Ring 1 3 0.000E+00 3
1.000E+00 3 --- 3 FRACA( 1)
R017 3 Ring 2 3 0.000E+00 3
2.732E-01 3 --- 3 FRACA( 2)
R017 3 Ring 3 3 0.000E+00 3
0.000E+00 3 --- 3 FRACA( 3)
R017 3 Ring 4 3 0.000E+00 3
0.000E+00 3 --- 3 FRACA( 4)
R017 3 Ring 5 3 0.000E+00 3
0.000E+00 3 --- 3 FRACA( 5)
R017 3 Ring 6 3 0.000E+00 3
0.000E+00 3 --- 3 FRACA( 6)
R017 3 Ring 7 3 0.000E+00 3
0.000E+00 3 --- 3 FRACA( 7)
R017 3 Ring 8 3 0.000E+00 3
0.000E+00 3 --- 3 FRACA( 8)
R017 3 Ring 9 3 0.000E+00 3
0.000E+00 3 --- 3 FRACA( 9)
R017 3 Ring 10 3 0.000E+00 3
0.000E+00 3 --- 3 FRACA(10)
R017 3 Ring 11 3 0.000E+00 3
0.000E+00 3 --- 3 FRACA(11)
R017 3 Ring 12 3 0.000E+00 3
0.000E+00 3 --- 3 FRACA(12)
3 3

```

```

R018 3 Fruits, vegetables and grain consumption (kg/yr) 3 1.600E+02 3
1.600E+02 3 --- 3 DIET(1)
R018 3 Leafy vegetable consumption (kg/yr) 3 1.400E+01 3
1.400E+01 3 --- 3 DIET(2)

```

R018	3	Milk consumption (L/yr)	3	9.200E+01	3
9.200E+01	3	---	3	DIET(3)	
R018	3	Meat and poultry consumption (kg/yr)	3	6.300E+01	3
6.300E+01	3	---	3	DIET(4)	
R018	3	Fish consumption (kg/yr)	3	5.400E+00	3
5.400E+00	3	---	3	DIET(5)	
R018	3	Other seafood consumption (kg/yr)	3	9.000E-01	3
9.000E-01	3	---	3	DIET(6)	
R018	3	Soil ingestion rate (g/yr)	3	3.650E+01	3
3.650E+01	3	---	3	SOIL	
R018	3	Drinking water intake (L/yr)	3	5.100E+02	3
5.100E+02	3	---	3	DWI	
R018	3	Contamination fraction of drinking water	3	1.000E+00	3
1.000E+00	3	---	3	FDW	
R018	3	Contamination fraction of household water	3	not used	3
1.000E+00	3	---	3	FHHW	
R018	3	Contamination fraction of livestock water	3	1.000E+00	3
1.000E+00	3	---	3	FLW	
R018	3	Contamination fraction of irrigation water	3	1.000E+00	3
1.000E+00	3	---	3	FIRW	
R018	3	Contamination fraction of aquatic food	3	5.000E-01	3
5.000E-01	3	---	3	FR9	
R018	3	Contamination fraction of plant food	3	-1	3-
1	3	0.500E+00	3	FPLANT	
R018	3	Contamination fraction of meat	3	-1	3-
1	3	0.101E+00	3	FMEAT	
R018	3	Contamination fraction of milk	3	-1	3-
1	3	0.101E+00	3	FMILK	
	3				3
	3				3
R019	3	Livestock fodder intake for meat (kg/day)	3	6.800E+01	3
6.800E+01	3	---	3	LFI5	
R019	3	Livestock fodder intake for milk (kg/day)	3	5.500E+01	3
5.500E+01	3	---	3	LFI6	
R019	3	Livestock water intake for meat (L/day)	3	5.000E+01	3
5.000E+01	3	---	3	LWI5	
R019	3	Livestock water intake for milk (L/day)	3	1.600E+02	3
1.600E+02	3	---	3	LWI6	
R019	3	Livestock soil intake (kg/day)	3	5.000E-01	3
5.000E-01	3	---	3	LSI	
R019	3	Mass loading for foliar deposition (g/m**3)	3	1.000E-04	3
1.000E-04	3	---	3	MLFD	
R019	3	Depth of soil mixing layer (m)	3	1.500E-01	3
1.500E-01	3	---	3	DM	
R019	3	Depth of roots (m)	3	9.000E-01	3
9.000E-01	3	---	3	DROOT	
R019	3	Drinking water fraction from ground water	3	1.000E+00	3
1.000E+00	3	---	3	FGWDW	
R019	3	Household water fraction from ground water	3	not used	3
1.000E+00	3	---	3	FGWHH	
R019	3	Livestock water fraction from ground water	3	1.000E+00	3
1.000E+00	3	---	3	FGWLW	
R019	3	Irrigation fraction from ground water	3	1.000E+00	3
1.000E+00	3	---	3	FGWIR	
	3				3
	3				3

```

R19B 3 Wet weight crop yield for Non-Leafy (kg/m**2) 3 7.000E-01 3
7.000E-01 3 --- 3 YV(1)
R19B 3 Wet weight crop yield for Leafy (kg/m**2) 3 1.500E+00 3
1.500E+00 3 --- 3 YV(2)
R19B 3 Wet weight crop yield for Fodder (kg/m**2) 3 1.100E+00 3
1.100E+00 3 --- 3 YV(3)
R19B 3 Growing Season for Non-Leafy (years) 3 1.700E-01 3
1.700E-01 3 --- 3 TE(1)
R19B 3 Growing Season for Leafy (years) 3 2.500E-01 3
2.500E-01 3 --- 3 TE(2)
R19B 3 Growing Season for Fodder (years) 3 8.000E-02 3
8.000E-02 3 --- 3 TE(3)

```

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Summary : Residential Scenario: Sludge; half acre contaminated zone;
EPA exposure factors
File : residential epa half acre.RAD

Site-Specific Parameter

Summary (continued)

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0 3 User 3
3 Used by RESRAD 3 Parameter
Menu 3 Parameter 3 Input 3
Default 3 (If different from user input) 3 Name

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AA
AA

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R19B 3 Translocation Factor for Non-Leafy 3 1.000E-01 3
1.000E-01 3 --- 3 TIV(1)
R19B 3 Translocation Factor for Leafy 3 1.000E+00 3
1.000E+00 3 --- 3 TIV(2)
R19B 3 Translocation Factor for Fodder 3 1.000E+00 3
1.000E+00 3 --- 3 TIV(3)
R19B 3 Dry Foliar Interception Fraction for Non-Leafy 3 2.500E-01 3
2.500E-01 3 --- 3 RDRY(1)
R19B 3 Dry Foliar Interception Fraction for Leafy 3 2.500E-01 3
2.500E-01 3 --- 3 RDRY(2)
R19B 3 Dry Foliar Interception Fraction for Fodder 3 2.500E-01 3
2.500E-01 3 --- 3 RDRY(3)
R19B 3 Wet Foliar Interception Fraction for Non-Leafy 3 2.500E-01 3
2.500E-01 3 --- 3 RWET(1)
R19B 3 Wet Foliar Interception Fraction for Leafy 3 2.500E-01 3
2.500E-01 3 --- 3 RWET(2)
R19B 3 Wet Foliar Interception Fraction for Fodder 3 2.500E-01 3
2.500E-01 3 --- 3 RWET(3)
R19B 3 Weathering Removal Constant for Vegetation 3 2.000E+01 3
2.000E+01 3 --- 3 WLAM

```

```

3 3
C14 3 C-12 concentration in water (g/cm**3) 3 not used 3
2.000E-05 3 --- 3 C12WTR
C14 3 C-12 concentration in contaminated soil (g/g) 3 not used 3
3.000E-02 3 --- 3 C12CZ
C14 3 Fraction of vegetation carbon from soil 3 not used 3
2.000E-02 3 --- 3 CSOIL
C14 3 Fraction of vegetation carbon from air 3 not used 3
9.800E-01 3 --- 3 CAIR

```

C14	³	C-14 evasion layer thickness in soil (m)	³	not used	³
3.000E-01	³	---	³	DMC	
C14	³	C-14 evasion flux rate from soil (1/sec)	³	not used	³
7.000E-07	³	---	³	EVSN	
C14	³	C-12 evasion flux rate from soil (1/sec)	³	not used	³
1.000E-10	³	---	³	REVSN	
C14	³	Fraction of grain in beef cattle feed	³	not used	³
8.000E-01	³	---	³	AVFG4	
C14	³	Fraction of grain in milk cow feed	³	not used	³
2.000E-01	³	---	³	AVFG5	
C14	³	DCF correction factor for gaseous forms of C14	³	not used	³
8.894E+01	³	---	³	CO2F	
	³		³		³
	³		³		³
STOR	³	Storage times of contaminated foodstuffs (days):	³		³
	³		³		³
STOR	³	Fruits, non-leafy vegetables, and grain	³	1.400E+01	³
1.400E+01	³	---	³	STOR_T(1)	
STOR	³	Leafy vegetables	³	1.000E+00	³
1.000E+00	³	---	³	STOR_T(2)	
STOR	³	Milk	³	1.000E+00	³
1.000E+00	³	---	³	STOR_T(3)	
STOR	³	Meat and poultry	³	2.000E+01	³
2.000E+01	³	---	³	STOR_T(4)	
STOR	³	Fish	³	7.000E+00	³
7.000E+00	³	---	³	STOR_T(5)	
STOR	³	Crustacea and mollusks	³	7.000E+00	³
7.000E+00	³	---	³	STOR_T(6)	
STOR	³	Well water	³	1.000E+00	³
1.000E+00	³	---	³	STOR_T(7)	
STOR	³	Surface water	³	1.000E+00	³
1.000E+00	³	---	³	STOR_T(8)	
STOR	³	Livestock fodder	³	4.500E+01	³
4.500E+01	³	---	³	STOR_T(9)	
	³		³		³
	³		³		³
R021	³	Thickness of building foundation (m)	³	not used	³
1.500E-01	³	---	³	FLOOR1	
R021	³	Bulk density of building foundation (g/cm**3)	³	not used	³
2.400E+00	³	---	³	DENSFL	
R021	³	Total porosity of the cover material	³	not used	³
4.000E-01	³	---	³	TPCV	
R021	³	Total porosity of the building foundation	³	not used	³
1.000E-01	³	---	³	TPFL	
R021	³	Volumetric water content of the cover material	³	not used	³
5.000E-02	³	---	³	PH2OCV	
R021	³	Volumetric water content of the foundation	³	not used	³
3.000E-02	³	---	³	PH2OFL	
R021	³	Diffusion coefficient for radon gas (m/sec):	³		³
	³		³		³
R021	³	in cover material	³	not used	³
2.000E-06	³	---	³	DIFCV	
R021	³	in foundation material	³	not used	³
3.000E-07	³	---	³	DIFFL	
R021	³	in contaminated zone soil	³	not used	³
2.000E-06	³	---	³	DIFCZ	

Summary : Residential Scenario: Sludge; half acre contaminated zone;
EPA exposure factors
File : residential epa half acre.RAD

Contaminated Zone Dimensions Initial Soil
Concentrations, pCi/g
AAAAAA
AAAAAA
Area: 2023.00 square meters Pu-239
2.040E+00
Thickness: 2.00 meters Pu-240 4.600E-
01
Cover Depth: 0.00 meters
0

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 1.000E+02 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at
Time (t)

AAAAAA
AAA
t (years): 0.000E+00 1.000E+00 3.000E+00 1.000E+01 3.000E+01
7.000E+01
TDOSE(t): 3.064E-01 3.064E-01 3.064E-01 3.062E-01 3.057E-01
3.047E-01
M(t): 3.064E-03 3.064E-03 3.064E-03 3.062E-03 3.057E-03
3.047E-03

0Maximum TDOSE(t): 3.064E-01 mrem/yr at t = 0.000E+00 years
1RESRAD, Version 6.21 T« Limit = 0.5 year 11/25/2002 14:11
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Summary : Residential Scenario: Sludge; half acre contaminated zone;
EPA exposure factors
File : residential epa half acre.RAD

Total Dose Contributions TDOSE(i,p,t) for
Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total

Dose At t = 0.000E+00 years
0 Water Independent Pathways
(Inhalation excludes radon)
0
Plant Ground Inhalation Radon
Meat Milk Soil
Radio- AAAAAA AAAAAA AAAAAA AAAAAA
AAAAAA AAAAAA AAAAAA AAAAAA
Nuclide mrem/yr fract. mrem/yr fract. mrem/yr fract. mrem/yr
fract. mrem/yr fract. mrem/yr fract. mrem/yr fract.
AAAAAA AAAAAA AAAAAA AAAAAA AAAAAA AAAAAA AAAAAA
AAAAAA AAAAAA AAAAAA AAAAAA AAAAAA AAAAAA AAAAAA
Pu-239 0.000E+00 0.0000 1.547E-02 0.0505 0.000E+00 0.0000 1.648E-
01 0.5378 6.854E-04 0.0022 9.779E-06 0.0000 6.910E-02 0.2255
Pu-240 0.000E+00 0.0000 3.489E-03 0.0114 0.000E+00 0.0000 3.716E-
02 0.1213 1.545E-04 0.0005 2.205E-06 0.0000 1.558E-02 0.0508
iiiiii iiiiii iiiiii iiiiii iiiiii iiiiii iiiiii
iiiiiii iiiiii iiiiii iiiiii iiiiii iiiiii iiiiii iiiiii

Total 0.000E+00 0.0000 1.896E-02 0.0619 0.000E+00 0.0000 2.020E-01 0.6590 8.399E-04 0.0027 1.198E-05 0.0000 8.468E-02 0.2763
0

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p) As mrem/yr and Fraction of Total

Dose At t = 0.000E+00 years Water Dependent

Plant	Water		Fish		Radon		mrem/yr
	Meat	fract.	Milk	fract.	All Pathways*	fract.	
Radio-	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.501E-01
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.064E-01

0*Sum of all water independent and dependent pathways.
1RESRAD, Version 6.21 T« Limit = 0.5 year 11/25/2002 14:11
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Summary : Residential Scenario: Sludge; half acre contaminated zone;
EPA exposure factors
File : residential epa half acre.RAD

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p) As mrem/yr and Fraction of Total

Dose At t = 1.000E+00 years Water Independent Pathways

Plant	Ground		Inhalation		Radon		mrem/yr
	Meat	fract.	Milk	fract.	Soil	fract.	
Radio-	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr
Pu-239	0.000E+00	0.0000	1.547E-02	0.0505	0.000E+00	0.0000	1.648E-01
Pu-240	0.000E+00	0.0000	3.488E-03	0.0114	0.000E+00	0.0000	3.715E-02
Total	0.000E+00	0.0000	1.896E-02	0.0619	0.000E+00	0.0000	2.019E-01

0

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)

As mrem/yr and Fraction of Total

Dose At t = 1.000E+00 years

0 Water Dependent

Pathways

Plant	Water		Fish		Radon		mrem/yr
	Meat	fract.	Milk	fract.	All Pathways*	fract.	
Radio-	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr
	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.500E-01
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.638E-02
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.064E-01

0*Sum of all water independent and dependent pathways.

1RESRAD, Version 6.21 T< Limit = 0.5 year 11/25/2002 14:11

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Summary : Residential Scenario: Sludge; half acre contaminated zone;

EPA exposure factors

File : residential epa half acre.RAD

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)

As mrem/yr and Fraction of Total

Dose At t = 3.000E+00 years

0 Water Independent Pathways

(Inhalation excludes radon)

Plant	Ground		Inhalation		Radon		mrem/yr
	Meat	fract.	Milk	fract.	Soil	fract.	
Radio-	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr
	0.000E+00	0.0000	1.547E-02	0.0505	0.000E+00	0.0000	1.648E-01
Pu-239	0.5378	6.853E-04	0.0022	9.777E-06	0.0000	6.908E-02	0.2255
Pu-240	0.000E+00	0.0000	3.487E-03	0.0114	0.000E+00	0.0000	3.714E-02
Total	0.000E+00	0.0000	1.896E-02	0.0619	0.000E+00	0.0000	2.019E-01

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)

As mrem/yr and Fraction of Total

Dose At t = 3.000E+00 years

0 Water Dependent

Pathways

Plant	Water		Fish		Radon		mrem/yr
	Meat	fract.	Milk	fract.	All Pathways*	fract.	
Radio-	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.0000
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.500E-01
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.064E-01

0*Sum of all water independent and dependent pathways.
 1RESRAD, Version 6.21 T« Limit = 0.5 year 11/25/2002 14:11
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Summary : Residential Scenario: Sludge; half acre contaminated zone;
 EPA exposure factors
 File : residential epa half acre.RAD

Total Dose Contributions TDOSE(i,p,t) for
 Individual Radionuclides (i) and Pathways (p)
 As mrem/yr and Fraction of Total

Dose At t = 1.000E+01 years
 0 Water Independent Pathways
 (Inhalation excludes radon)

Plant	Ground		Inhalation		Radon		mrem/yr
	Meat	fract.	Milk	fract.	Soil	fract.	
Radio-	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr
Pu-239	0.000E+00	0.0000	1.546E-02	0.0505	0.000E+00	0.0000	1.647E-01
Pu-240	0.000E+00	0.0000	3.484E-03	0.0114	0.000E+00	0.0000	3.710E-02
Total	0.000E+00	0.0000	1.895E-02	0.0619	0.000E+00	0.0000	2.018E-01

Total Dose Contributions TDOSE(i,p,t) for
 Individual Radionuclides (i) and Pathways (p)
 As mrem/yr and Fraction of Total

Dose At t = 1.000E+01 years
 0 Water Dependent Pathways

Plant	Water		Fish		Radon		mrem/yr
	Meat	fract.	Milk	fract.	All Pathways*	fract.	
Radio-	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	AAAAAAAAAAAAAAAA	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr

Pu-239 0.000E+00 0.0000 0.000E+00 0.0000 0.000E+00 0.0000
0.000E+00 0.0000 0.000E+00 0.0000 0.000E+00 0.0000 2.496E-01 0.8164
Pu-240 0.000E+00 0.0000 0.000E+00 0.0000 0.000E+00 0.0000
0.000E+00 0.0000 0.000E+00 0.0000 0.000E+00 0.0000 5.614E-02 0.1836
IIIIIIII IIIIIIIII IIIIII IIIIIIIII IIIIII IIIIIIIII IIIIII
IIIIIIII IIIIII IIIIIIIII IIIIII IIIIIIIII IIIIII IIIIIIIII IIIIII
Total 0.000E+00 0.0000 0.000E+00 0.0000 0.000E+00 0.0000
0.000E+00 0.0000 0.000E+00 0.0000 0.000E+00 0.0000 3.057E-01 1.0000
0*Sum of all water independent and dependent pathways.
1RESRAD, Version 6.21 T« Limit = 0.5 year 11/25/2002 14:11
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Summary : Residential Scenario: Sludge; half acre contaminated zone;
EPA exposure factors
File : residential epa half acre.RAD

Total Dose Contributions TDOSE(i,p,t) for
Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total

Dose At t = 7.000E+01 years

		Water Independent Pathways					
		Ground		Inhalation		Radon	
Plant		Meat		Milk		Soil	
Radio-	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr
fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr
AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA
AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA
Pu-239	0.000E+00	0.0000	1.540E-02	0.0505	0.000E+00	0.0000	1.640E-01
01	0.5383	6.823E-04	0.0022	9.735E-06	0.0000	6.878E-02	0.2257
Pu-240	0.000E+00	0.0000	3.454E-03	0.0113	0.000E+00	0.0000	3.679E-02
02	0.1207	1.530E-04	0.0005	2.184E-06	0.0000	1.543E-02	0.0506
IIIIIIII	IIIIIIIIII	IIIIIII	IIIIIIIIII	IIIIIII	IIIIIIIIII	IIIIIII	IIIIIIIIII
IIIIIIIIII	IIIIIII	IIIIIIIIII	IIIIIII	IIIIIIIIII	IIIIIII	IIIIIIIIII	IIIIIII
Total	0.000E+00	0.0000	1.886E-02	0.0619	0.000E+00	0.0000	2.008E-01
01	0.6590	8.353E-04	0.0027	1.192E-05	0.0000	8.421E-02	0.2763
0							

Total Dose Contributions TDOSE(i,p,t) for
Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total

Dose At t = 7.000E+01 years

		Water Dependent Pathways					
		Water		Fish		Radon	
Plant		Meat		Milk		All Pathways*	
Radio-	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr
fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr
AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA
AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA	AAAAA
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.489E-01
0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.0000	0.8168
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.582E-02
0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.0000	0.1832

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iiiiiiii iiiiiiiiii iiiiii iiiiiiiiii iiiiii iiiiiiiiii iiiiii
iiiiiiiiiii iiiiii iiiiiiiiii iiiiii iiiiiiiiii iiiiii iiiiiiiiii iiiiii
Total 0.000E+00 0.0000 0.000E+00 0.0000 0.000E+00 0.0000
0.000E+00 0.0000 0.000E+00 0.0000 0.000E+00 0.0000 3.047E-01 1.0000
0*Sum of all water independent and dependent pathways.
1RESRAD, Version 6.21 T« Limit = 0.5 year 11/25/2002 14:11
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Summary : Residential Scenario: Sludge; half acre contaminated zone;
EPA exposure factors
File : residential epa half acre.RAD

Dose/Source Ratios Summed Over All Pathways
Parent and Progeny Principal Radionuclide Contributions

Indicated			DSR(j,t)			
Parent	Product	Branch				
(i)	(j)	Fraction*	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01
Pu-239	Pu-239	1.000E+00	1.226E-01	1.226E-01	1.226E-01	1.225E-01
Pu-239	U-235	1.000E+00	2.199E-11	6.720E-11	1.577E-10	4.721E-10
Pu-239	Pa-231	1.000E+00	5.454E-15	3.994E-14	2.150E-13	1.930E-12
Pu-239	Ac-227	1.000E+00	1.185E-17	1.549E-16	1.643E-15	3.896E-14
Pu-239	äDSR(j)		1.226E-01	1.226E-01	1.226E-01	1.225E-01
Pu-240	Pu-240	1.000E+00	1.226E-01	1.226E-01	1.225E-01	1.224E-01
Pu-240	U-236	1.000E+00	1.074E-09	3.279E-09	7.689E-09	2.301E-08
Pu-240	Th-232	1.000E+00	1.072E-19	7.173E-19	3.707E-18	3.266E-17
Pu-240	Ra-228	1.000E+00	3.181E-20	5.009E-19	5.727E-18	1.282E-16
Pu-240	Th-228	1.000E+00	2.721E-22	5.040E-21	7.359E-20	2.443E-18
Pu-240	äDSR(j)		1.226E-01	1.226E-01	1.225E-01	1.224E-01

*Branch Fraction is the cumulative factor for the j't principal radionuclide daughter: CUMBRF(j) = BRF(1)*BRF(2)* ... BRF(j).
The DSR includes contributions from associated (half-life ó 0.5 yr) daughters.

0

Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 1.000E+02 mrem/yr

0Nuclide	(i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01
		ÄÄÄÄÄÄÄÄ	ÄÄÄÄÄÄÄÄ	ÄÄÄÄÄÄÄÄ	ÄÄÄÄÄÄÄÄ	ÄÄÄÄÄÄÄÄ

Pu-239	8.158E+02	8.159E+02	8.160E+02	8.163E+02	8.174E+02
8.196E+02					
Pu-240	8.158E+02	8.160E+02	8.162E+02	8.170E+02	8.193E+02
8.240E+02					
íííííííí	íííííííí	íííííííí	íííííííí	íííííííí	íííííííí
íííííííí					
0					

Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)
and Single Radionuclide Soil Guidelines G(i,t) in pCi/g
at tmin = time of minimum single radionuclide soil guideline
and at tmax = time of maximum total dose = 0.000E+00 years

0Nuclide	Initial	tmin	DSR(i,tmin)	G(i,tmin)	DSR(i,tmax)
G(i,tmax)	(i)	(pCi/g)	(years)	(pCi/g)	(pCi/g)
	AAAAAAA	AAAAAAA	AAAAAAAAAAAAAAA	AAAAAAA	AAAAAAA
	AAAAAAA	AAAAAAA	AAAAAAAAAAAAAAA	AAAAAAA	AAAAAAA
Pu-239	2.040E+00	0.000E+00	1.226E-01	8.158E+02	1.226E-01
8.158E+02					
Pu-240	4.600E-01	0.000E+00	1.226E-01	8.158E+02	1.226E-01
8.158E+02					
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1RESRAD, Version 6.21 T« Limit = 0.5 year 11/25/2002 14:11
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Summary : Residential Scenario: Sludge; half acre contaminated zone;
EPA exposure factors
File : residential epa half acre.RAD

Individual Nuclide Dose Summed Over All Pathways
Parent Nuclide and Branch Fraction Indicated

0Nuclide	Parent	BRF(i)	DOSE(j,t), mrem/yr			
(j)	(i)		t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01
3.000E+01	7.000E+01					
AAAAAAA						
AAAAAAA						
Pu-239	Pu-239	1.000E+00	2.501E-01	2.500E-01	2.500E-01	2.499E-01
2.496E-01	2.489E-01					
0U-235	Pu-239	1.000E+00	4.486E-11	1.371E-10	3.216E-10	9.630E-10
2.758E-09	6.188E-09					
0Pa-231	Pu-239	1.000E+00	1.113E-14	8.147E-14	4.386E-13	3.938E-12
3.266E-11	1.678E-10					
0Ac-227	Pu-239	1.000E+00	2.417E-17	3.161E-16	3.352E-15	7.948E-14
1.605E-12	1.450E-11					
0Pu-240	Pu-240	1.000E+00	5.638E-02	5.638E-02	5.636E-02	5.630E-02
5.614E-02	5.582E-02					
0U-236	Pu-240	1.000E+00	4.940E-10	1.508E-09	3.537E-09	1.059E-08
3.030E-08	6.786E-08					
0Th-232	Pu-240	1.000E+00	4.931E-20	3.299E-19	1.705E-18	1.502E-17
1.248E-16	6.523E-16					
0Ra-228	Pu-240	1.000E+00	1.463E-20	2.304E-19	2.634E-18	5.897E-17
9.379E-16	6.480E-15					
0Th-228	Pu-240	1.000E+00	1.252E-22	2.318E-21	3.385E-20	1.124E-18
2.342E-17	1.779E-16					
íííííííí	íííííííí	íííííííííííííííííí	íííííííííííííííííí	íííííííííííííííííí	íííííííííííííííííí	íííííííííííííííííí
íííííííííííííííííí	íííííííííííííííííí					

BRF(i) is the branch fraction of the parent nuclide.

0Nuclide Parent		BRF(i)	Individual Nuclide Soil Concentration Parent Nuclide and Branch Fraction Indicated			
(j)	(i)		S(j,t), pCi/g			
			t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01
3.000E+01	7.000E+01					
AAAAAAA	AAAAAAA	AAAAAAA	AAAAAAA	AAAAAAA	AAAAAAA	AAAAAAA
AAAAAAA	AAAAAAA					
Pu-239	Pu-239	1.000E+00	2.040E+00	2.040E+00	2.040E+00	2.039E+00
2.036E+00	2.031E+00					
0U-235	Pu-239	1.000E+00	0.000E+00	2.008E-09	6.014E-09	1.994E-08
5.891E-08	1.334E-07					
0Pa-231	Pu-239	1.000E+00	0.000E+00	2.123E-14	1.907E-13	2.104E-12
1.856E-11	9.712E-11					
0Ac-227	Pu-239	1.000E+00	0.000E+00	2.234E-16	5.918E-15	2.053E-13
4.651E-12	4.340E-11					
0Pu-240	Pu-240	1.000E+00	4.600E-01	4.599E-01	4.598E-01	4.593E-01
4.580E-01	4.554E-01					
0U-236	Pu-240	1.000E+00	0.000E+00	1.361E-08	4.075E-08	1.351E-07
3.988E-07	9.015E-07					
0Th-232	Pu-240	1.000E+00	0.000E+00	3.357E-19	3.018E-18	3.341E-17
2.975E-16	1.586E-15					
0Ra-228	Pu-240	1.000E+00	0.000E+00	1.309E-20	3.331E-19	1.018E-17
1.768E-16	1.250E-15					
0Th-228	Pu-240	1.000E+00	0.000E+00	1.111E-21	7.506E-20	5.333E-18
1.419E-16	1.147E-15					

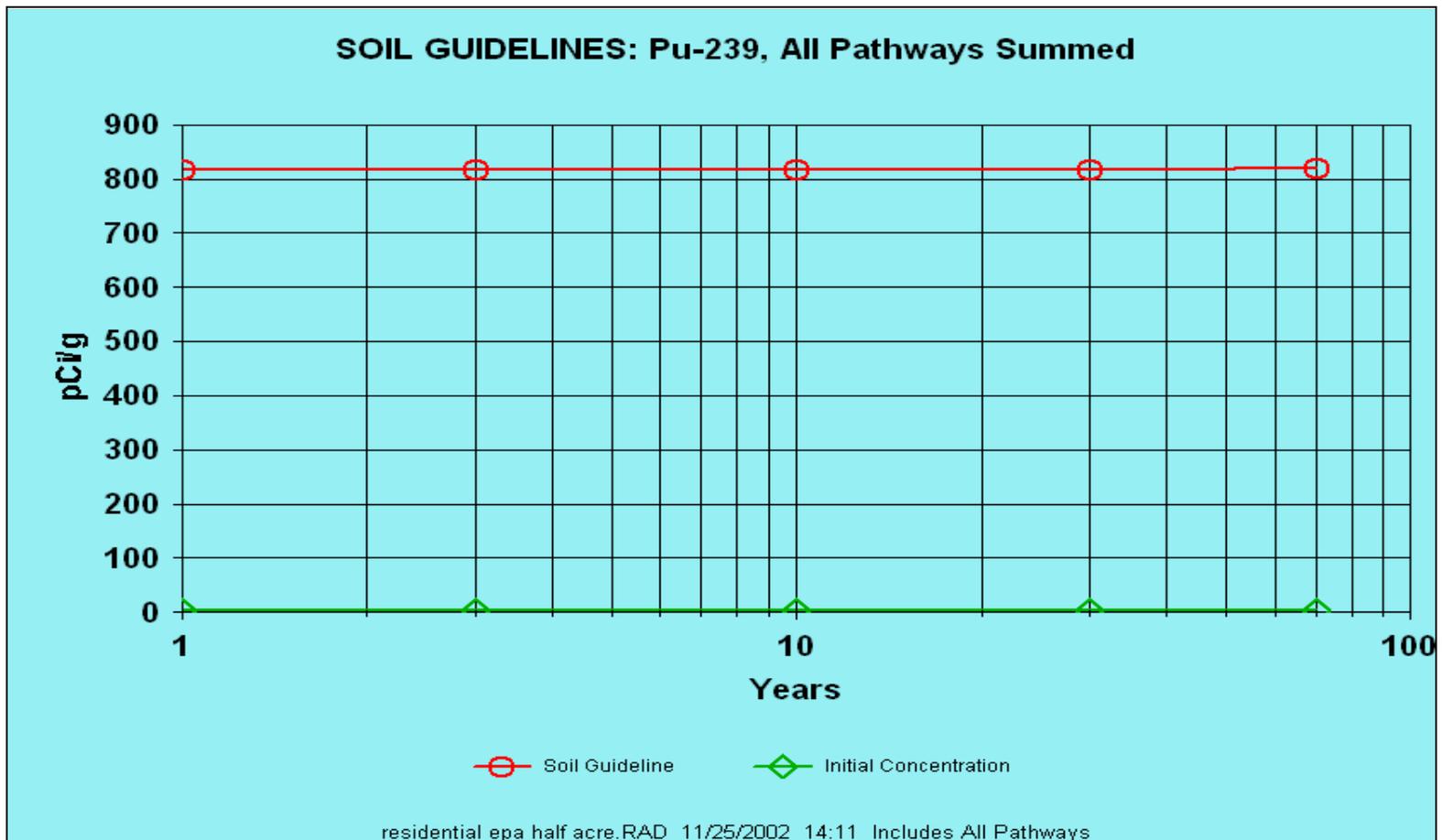


Figure A-1. RESRAD output showing soil guideline for Pu 239 based on all pathways/exposure routes (ingestion, inhalation, and external exposure) and a 100 mrem/year dose. The soil guideline is the Pu 239 concentration that is required to produce an annual dose of mrem/year. The initial concentration is 2.5 pCi/g. Exposure factors and model parameters are as described in the text.

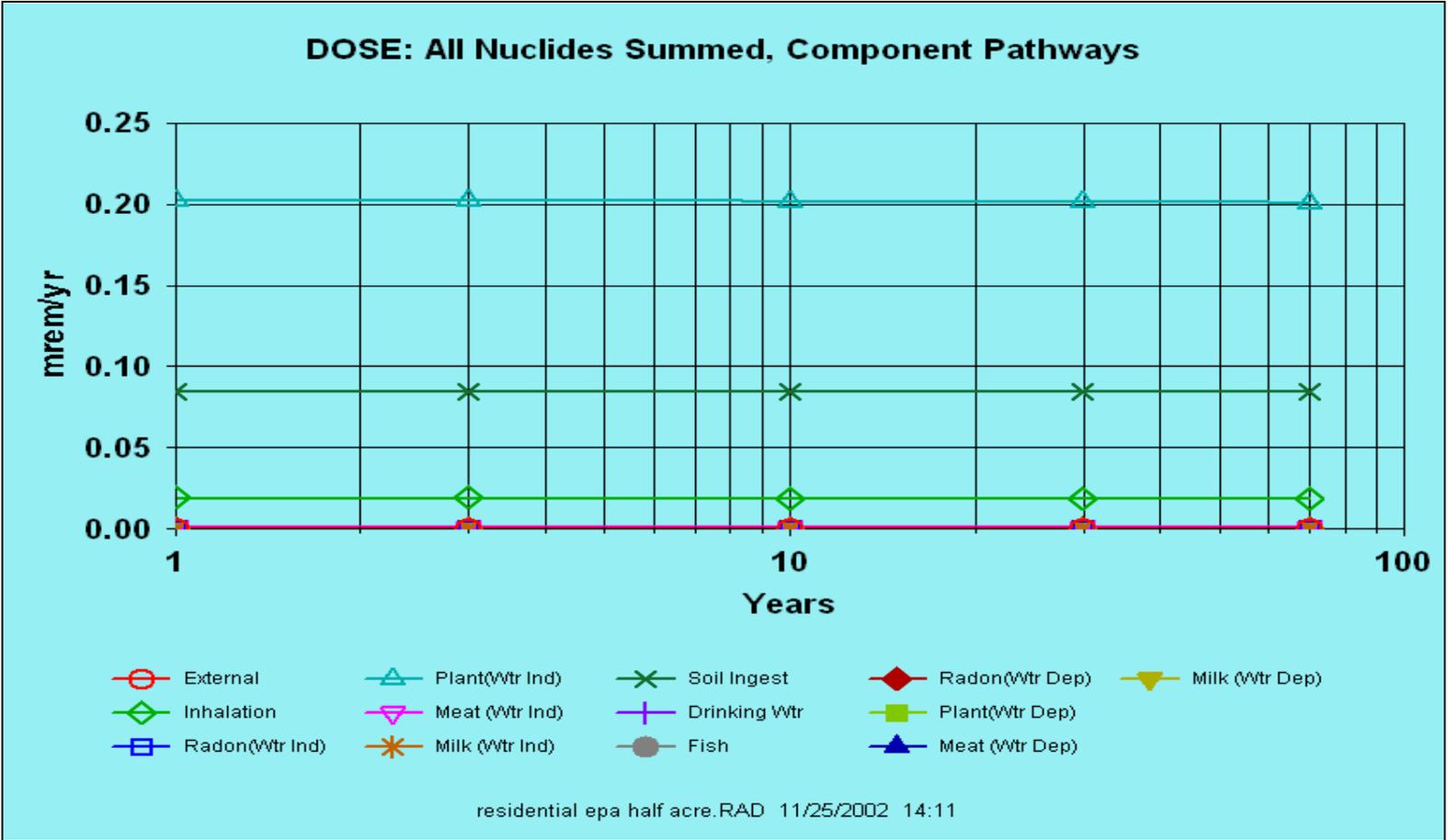


Figure A-2. RESRAD output showing dose contributions from different exposure pathways or routes. These doses are based on an average soil concentration of 2.5 pCi/g Pu 239 and Pu 240. The total dose is 0.31 mrem/year as shown in Figure 2. Consumption of plants (food crops) accounts for about 65% of the total dose, soil ingestion about 26% of the dose, and inhalation of dust accounting for about 6% of the dose.

Appendix 4. Gross Alpha and Nuclide-specific monitoring Data

		CaRHB		LLNL +	LLNL +	LLNL GA	LLNL Pu 239	LLNL +		
		digester sludge		sewer effluent	dried sludge	digester sludge pCi/g or pCi/L	digester sludge	annual releases (Gross Alpha except 1973)		
		pCi/g		pCi/L	pCi/g	pCi/L	pCi/L	Ci/yr		
1960	Jan	0.15	wet wt.	<38						
		0.15	wet wt.	<38						
		0.15	wet wt.	<38						
	Apr		wet wt.	<38						
			wet wt.	<38						
			wet wt.	<38						
	Jul		wet wt.	<38						
			wet wt.	<38						
			wet wt.	<38						
	Oct		wet wt.							
			wet wt.							
			wet wt.							
1961	Jan		wet wt.	18.7*	<7.2					
			wet wt.	18.7*	<7.2					
			wet wt.	18.7*	<7.2					
	Apr		wet wt.	18.7*	<7.2					
			wet wt.	18.7*	<7.2					
			wet wt.	18.7*	<7.2					
	Jul		wet wt.		<7.2					
			wet wt.		<7.2					
		0.1	wet wt.		<7.2					
	Oct	0.15	wet wt.		4.5					
		0.15	wet wt.		4.5					
		0.3	wet wt.		4.5					
1962	Jan	0.15	wet wt.		4.6					

	CaRHB		LLNL +	LLNL +	LLNL GA	LLNL Pu 239	LLNL +		
	digester sludge		sewer effluent	dried sludge	digester sludge pCi/g or pCi/L	digester sludge	annual releases (Gross Alpha except 1973)		
	pCi/g		pCi/L	pCi/g	pCi/L	pCi/L	Ci/yr		
	0.2	wet wt.		4.6					
	0.15	wet wt.		4.6					
Apr	0.15	wet wt.		4.6					
	0.15	wet wt.		4.6					
	0.15	wet wt.		4.6					
Jul	0.15	wet wt.							
	0.15	wet wt.							
		wet wt.							
Oct		wet wt.							
		wet wt.							
		wet wt.							
1963	Jan	wet wt.	8.9	6			1.10E-03		
		wet wt.	8.9	6			1.10E-03		
		wet wt.	8.9	6			1.10E-03		
Apr		wet wt.	8.9	6			1.10E-03		
			8.9	6			1.10E-03		
			8.9	6			1.10E-03		
Jul			6.1	6.7			1.10E-03		
			6.1	6.7			1.10E-03		
			6.1	6.7			1.10E-03		
Oct			6.1	6.7			1.10E-03		
			6.1	6.7			1.10E-03		
	11.1		6.1	6.7			1.10E-03		
1964	Jan	23.9	29	12			6.40E-03		
	11.6		29	12			6.40E-03		
	21.9		29	12			6.40E-03		
Apr	0.15		29	12			6.40E-03		

		CaRHB		LLNL +	LLNL +	LLNL GA	LLNL Pu 239	LLNL +		
		digester sludge		sewer effluent	dried sludge	digester sludge pCi/g or pCi/L	digester sludge pCi/L	annual releases (Gross Alpha except 1973) Ci/yr		
		pCi/g		pCi/L	pCi/g	pCi/L	pCi/L			
				29	12			6.40E-03		
		296.9		29	12			6.40E-03		
	Jul	173		92	34			6.40E-03		
				92	34			6.40E-03		
				92	34			6.40E-03		
	Oct			92	34			6.40E-03		
				92	34			6.40E-03		
		94		92	34			6.40E-03		
1965	Jan	84		20.4	39			3.60E-03		
		39		20.4	39			3.60E-03		
		52		20.4	39			3.60E-03		
	Apr			20.4	39			3.60E-03		
				20.4	39			3.60E-03		
				20.4	39			3.60E-03		
	Jul			5.4	60			3.60E-03		
				5.4	60			3.60E-03		
				5.4	60			3.60E-03		
	Oct			5.4	60			3.60E-03		
		23		5.4	60			3.60E-03		
				5.4	60			3.60E-03		
1966	Jan			6	42			3.00E-03		
				6	42			3.00E-03		
		64		6	42			3.00E-03		
	Apr	8	est.	6	42			3.00E-03		
		31	est.	6	42			3.00E-03		
		26		6	42			3.00E-03		
	Jul	7	est.	9	17			3.00E-03		

	CaRHB		LLNL +	LLNL +	LLNL GA	LLNL Pu 239	LLNL +		
	digester sludge		sewer effluent	dried sludge	digester sludge pCi/g or pCi/L	digester sludge	annual releases (Gross Alpha except 1973)		
	pCi/g		pCi/L	pCi/g	pCi/L	pCi/L	Ci/yr		
	1	est.	9				6.00E-03		
	16	est.	9				6.00E-03		
1969	Jan	6	19**		6#		7.90E-03		
		12	19**		5#		7.90E-03		
		14	19**		3#		7.90E-03		
	Apr	6	19**		8#		7.90E-03		
		21	19**		13#		7.90E-03		
		8	19**		11#		7.90E-03		
	Jul				18#		7.90E-03		
					20#		7.90E-03		
					21#		7.90E-03		
	Oct				23#		7.90E-03		
					45#		7.90E-03		
					39#		7.90E-03		
1970	Jan		est.	7.6	22#		3.60E-03		
			est.	7	22#		3.60E-03		
			est.	4.6	17#		3.60E-03		
	Apr		est.	3.5	16#		3.60E-03		
			est.	20			3.60E-03		
			est.	20			3.60E-03		
	Jul		est.	8			3.60E-03		
			est.	4			3.60E-03		
			est.	<1.2			3.60E-03		
	Oct		est.	<1.2			3.60E-03		
			est.	4			3.60E-03		
			est.	7			3.60E-03		
1971	Jan						2.80E-03		

	CaRHB	LLNL +	LLNL +	LLNL GA	LLNL Pu 239	LLNL +		
	digester sludge pCi/g	sewer effluent pCi/L	dried sludge pCi/g	digester sludge pCi/g or pCi/L	digester sludge pCi/L	annual releases (Gross Alpha except 1973) Ci/yr		
				160		2.80E-03		
				150		2.80E-03		
Apr				190		2.80E-03		
				210		2.80E-03		
				280		2.80E-03		
Jul				220		2.80E-03		
				260		2.80E-03		
				280		2.80E-03		
Oct				110		2.80E-03		
				220		2.80E-03		
				180		2.80E-03		
1972 Jan				430		2.40E-03		
				190		2.40E-03		
				280		2.40E-03		
Apr				240		2.40E-03		
				250		2.40E-03		
				390		2.40E-03		
Jul				220		2.40E-03		
				280		2.40E-03		
				330		2.40E-03		
Oct				200		2.40E-03		
				430		2.40E-03		
				330	Pu 239 pCi./L	2.40E-03		Pu 238 pCi/L
1973 Jan			2.6	430	9.9	2.00E-04	Pu 239	3.2
			2.6	260	6.3	2.00E-04	Pu 239	2.2
			2.6	210	8.3	2.00E-04	Pu 239	3.6
Apr				210	7.8	2.00E-04	Pu 239	3.6

	CaRHB	LLNL +	LLNL +	LLNL GA	LLNL Pu 239	LLNL +		
	digester sludge	sewer effluent	dried sludge	digester sludge	digester sludge	annual releases (Gross Alpha except 1973)		
	pCi/g	pCi/L	pCi/g	pCi/g or pCi/L	pCi/L	Ci/yr		
				210	6.8	2.00E-04	Pu 239	2.5
				290	12	2.00E-04	Pu 239	2.3
Jul				200	7.4	2.00E-04	Pu 239	1.9
				450	8.9	2.00E-04	Pu 239	2.2
				330	3.6	2.00E-04	Pu 239	0.87
Oct				340	5.4	2.00E-04	Pu 239	0.89
				210	4.4	2.00E-04	Pu 239	0.63
				250	6.8	2.00E-04	Pu 239	0.67

CaRHB- LWRP digester gross alpha concentrations for the years 1960 through 1969 are from data sheets entitled “Gross Radioactivity in Sewage Samples: 1960-1969, published in the Radiological Health News, California Department of Health Services, Radiation Health Branch.

-CaRHB Measurements of “No Significant Activity” are reported in this spreadsheet as values of 0.15 pCi/g to facilitate data plotting.

-Values noted as estimated (est.) “When the counting rate of the sample is not equal to at least twice the 0.95 error, the value reported is the best available estimate, but is not statistically significant. Where the asterisk appears without a value, no activity was detected.” (reported as 0.15 in this spreadsheet).

- The 1964 CaRHB report contains this note “Beginning May 1963 all sewage sludge has been reported in picocuries per gram of dry sludge. Before that date it was reported in picocuries per gram of wet sludge. The footnote should be corrected.”

LLNL- All data labeled as LLNL data are from published annual and semi-annual reports for the years 1960 through 1973. These include reports published as the Lawrence Radiation Laboratory or the Lawrence Livermore Laboratory, or the Lawrence Livermore National Laboratory. LLNL analyses of sludge from digester 1 are reported as pCi/L or pCi/g, as specified above.

* following value denotes “Limits of Detection”.

** Maximum monthly average for 6 month reporting period.

+ 6-month or annual average values are shown as repeated values.

Average of digester 1 and digester 2.

Appendix 5: The Use of Radiation Dose vs. Risk in Public Health Determinations

The Agency for Toxic Substances and Disease Registry (ATSDR) Division of Health Assessment and Consultation Federal Facilities Assessment Branch (FFAB) has evaluated the scientific basis for the use of radiation dose and the expression of this dose in terms of risk in the preparation of public health documents. This appendix reviews the concepts of dose vs. risk and establishes the rationale for the use of dose in public health evaluations pertaining to radiation, radiation exposure and radiation dose.

To properly evaluate the dose and risk issues associated with radiation exposure, the terms dose and risk should be clearly defined. The International Society for Risk Analysis (www.sra.org) defines **risk** as “*The potential for realization of unwanted, adverse consequences to human life, health, property, or the environment; estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event given that it has occurred.*” As defined, risk is a statistical concept.

ATSDR defines **dose** as “*The amount of a substance to which a person may be exposed, usually on a daily basis. Dose is often explained as “amount of substance(s) per body weight per day”.* Doses are the basis for determining levels of exposure that may cause adverse health effects and may be directly related to the assessment of public health.

Risk assessments compared to public health assessments

The US Environmental Protection Agency (EPA) develops regulations based on risk. They also develop health risk assessments. The EPA conducts these assessments for both specific sites (such as Superfund sites) and specific chemicals. In site assessments, the EPA uses a four-part process to estimate the *chance* that contact with chemicals from that site will harm people now or in the future. These steps include data collection and evaluation, exposure assessment, followed by toxicity assessment and then risk characterization to reveal which chemicals are posing risks and what the health risks are.

In contrast to the EPA, ATSDR develops its public health documents on a scientific review of toxicological, radiological health, peer-reviewed science, and other reliable sources of information to evaluate the impact of hazardous chemicals and radiation on the public health. The ATSDR public health assessment differs from the EPA risk assessment in many ways. Perhaps the most important difference between ATSDR public health assessments and EPA risk assessments is that ATSDR bases its findings on *site-specific factors* including demographics, realistic land use, realistic pathway analysis, and other pertinent data related to the site. As defined, the ATSDR health assessment is the *evaluation of data and information on the release of hazardous substances into the environment in order to assess any current or future impact on public health, develop health advisories or other recommendations, and identify studies or actions needed to evaluate and mitigate or prevent human health effects* (55 Federal Register 5136, February 13, 1990, as codified at 42 Code of Federal Regulations Part 90).

General Accounting Office Review of the basis for Radiation Standards

The General Accounting Office (GAO) released a 1994 report reviewing the US radiation standards and radiation protection issues (GAO 1994). The GAO further refined their results in 2000 (GAO 2000). The findings of 1994 indicated a general lack of federal agency consensus on acceptable radiation risk to the public. Among the reasons for this lack of consensus is that agencies have different missions and Congressional mandates. For example, the EPA implements a risk-based radiation protection approach; whereas, the US Nuclear Regulatory Commission (NRC) approaches the radiation protection issue with a dose-based framework. The EPA attempts to address individual contamination sources, whether chemical and/or radioactive materials thus protecting both human health and environmental resources¹⁴.

Generally, the EPA sets a risk of 1 in a million that an individual will develop cancer in a lifetime as a goal for remediation and has considered a risk of greater than 1 in 10,000 to be potentially excessive. The GAO described the approach used by the EPA as a “bottom up approach” setting a relatively restrictive risk goal to be pursued through the best available technology. This approach also permits a less restrictive limit in site-specific situations. In contrast, NRC approach is based on a human health protection approach¹⁵. The GAO described this methodology as a “top down approach.” Compared with EPA, NRC sets a relatively less restrictive dose limit but reduces doses (and risks) well below the limit in site-specific situations where the reductions are “reasonably achievable.” This is the basis of the NRC ALARA methodology (As Low As Reasonably Achievable).

The GAO report (GAO 2000) reported that “conclusive evidence of radiation effects is lacking below a total dose of about 5,000 to 10,000 millirem, according to the scientific literature” and this was also the consensus of experts they interviewed. At these levels of radiation doses, expert organizations estimate radiation risks using complex models of existing data¹⁶. Furthermore, regulatory agencies, using the linear no-threshold hypothesis assume there is a risk at any radiation exposure. Table 2 from the GAO

¹⁴ EPA based its protection approach on the regulation of chemicals, many of which have a mode of action generally less understood than the mode of action of radiation exposure and dose.

¹⁵The approach used by the NRC is derived from years of experience in estimating radiation-specific risks from the former Atomic Energy Commission, international organizations and internationally recommended radiation dose limitations associated with a risk assessment framework that factors in the naturally occurring radiation exists naturally in the worldwide environment.

¹⁶ For example, a 1990 study by a National Academy of Sciences committee, called BEIR V, estimated that, at the 90-percent statistical confidence interval, out of 100,000 adults exposed to 100 millirem a year of radiation over a lifetime, anywhere from 410 to 980 men and 500 to 930 women might die of cancer caused by the exposure. This confidence interval assumes the validity of the linear model and reflects the uncertainty of inputs to the model (NRC 1990).

reports shows that federal radiation doses and risks are widely distributed even among the same agency, dependent on mission.

Standard or guideline	Agency	Limit	Risk
General public limit	NRC	100 mrem/y	1 in 300
Air pollution	EPA	10 mrem/y	1 in 3000
CERCLA	EPA	15 mrem/y	1 in 10,000 to 1 in a million
Risk per rem/year		0.0005	
Background of 360 millirem per year, 70 years			~ 1 in 80 (1.26E-2)

Table 2. Federal standards or guidelines, radiation limits, and assumed risk values. Data derived from Table 1, GAO 1994.

Discussion of the Linear No Threshold Model

The health effects induced by radiation doses have been studied for over 100 years. In contrast, the risk-based standards are derived from hypothetical models utilized for low level radiation doses and dose effects¹⁷. The models used by agencies such as the EPA, NRC, Department of Energy, and others are based on atomic bomb survivors, radium dial painters of the early 20th century, medical treatments, uranium miners, accidental radiation exposure individuals, and other studies of large populations who have received various doses of ionization radiation of several types for various reasons. Unfortunately, scientists have had much difficulty extrapolating the known effects from the high radiation doses to lower, less well-verified dose related health effects, especially those associated with radiation exposures marginally exceeding backgrounds.

The linear no-threshold model (LNT) has been accepted as a mathematically simple working hypothesis to drive radiation protection regulations because it will not underestimate risks, yet it may be conservative. The LNT states that even the smallest radiation exposure carries a quantifiable cancer risk. The regulatory agencies use LNT for risk assessments, regulatory impact analyses, cost-benefit analyses, and other studies to support decision-making. In using the model, they are able to estimate risk reductions and hypothetical lives saved from regulating at a given exposure level. At issue with LNT and with its use to establish risk is the evidence that the response relationship may vary in individuals, and with the type of radiation, rate of radiation exposure, type of cancer, body organs exposed, sex, and/or age at exposure. These unknowns add to the issue of uncertainty in the risk numbers. The GAO (1994; 2000) during their investigation “found

¹⁷ The NCRP has defined low dose as less than 20 rads (0.2 Gray; Gy) and low dose rate as less than 0.1 Gy per day (NCRP, 1997).

considerable agreement among regulators and scientists that the linear model may be a conservative “fit” to the data, and is unlikely to underestimate risks. However, some said the data support the existence of a safety threshold below which there are no risks, and others said low levels of radiation can be beneficial to health.”

As the accepted model, LNT has been used for many years for regulating low-level radiation although its scientific basis has come under scrutiny in recent years by national and international organizations such as the American Nuclear Society and the Health Physics Society and by individual scientists and private organizations. Therefore, many scientists want conclusive evidence of radiation effects at the lower levels of exposure where the impact of LNT is greatest. The GAO (2000) stated “The consensus view we encountered is that the research data on low-level radiation effects are inadequate either to establish a safety threshold or to exclude the possibility of no effects. Scientists we contacted and scientific literature we examined generally did not indicate that any one model clearly best fit the overall data.”

Figure A-3 (Figure 1 in 2000 GAO report) shows the representative knowledge base of radiation effects in relation to radiation dose. Besides the 4 possible dose response curves indicated on the figure, it also shows that above a dose of 10,000 millirem (10 rem, 0.1 Sv) or more, the data are conclusive with respect to the identification of health effects resulting from radiation exposure. Between 5,000 and 10,000 mrem per year, the data are not clear as to the health effects. Below 5,000 mrem, health effects have not been observed, only assumed to occur. Therefore, the risk associated with a dose that approaches background, 360 mrem/year (7% of 5,000 mrem) is essentially impossible to measure.

Figure 2: Four Models of Low-Level Radiation Effects

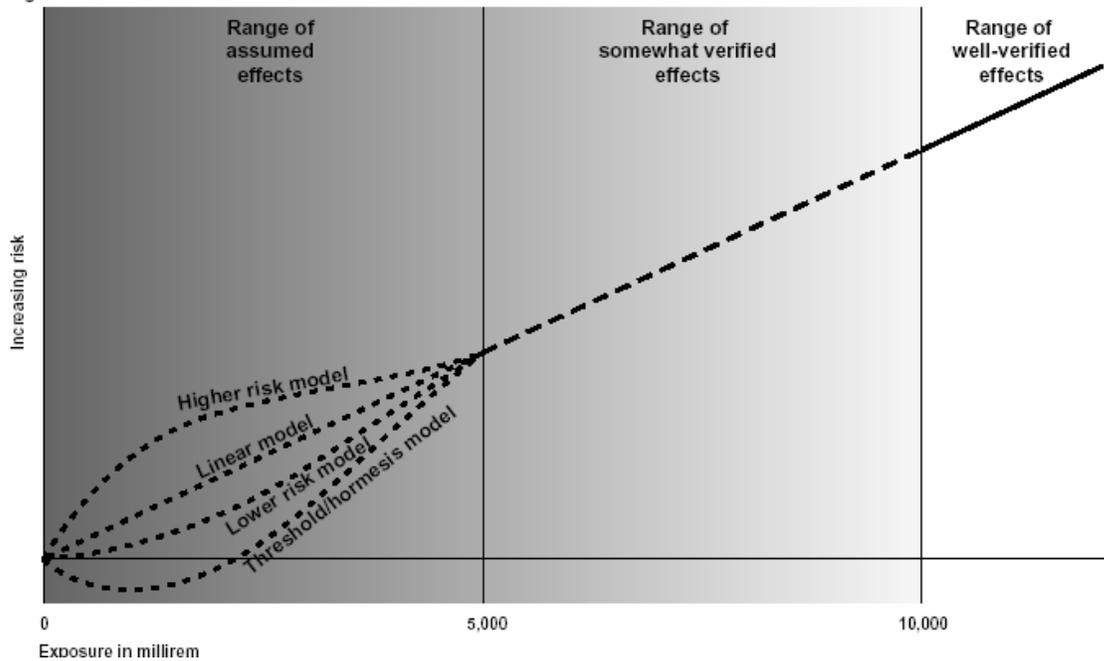


Figure A-3. Four models of low-level radiation effects from GAO 2000 report. Nonetheless, there is general acceptance of the risk coefficient (referred to as detriment by the ICRP) used to calculate these risk numbers. That coefficient is 0.05% per rem per year of exposure for low dose, low dose rate (EPA 1994; ICRP 1990; NCRP 1993). The coefficient is for cancer mortality.

Do the data fit the LNT Model: Implications for linear risk

As seen in Figure A-3, a major factor in dealing with risk is the shape of the dose response curve at doses less than 5,000 mrem. For various types of radiation-induced cancers, the data may not fit the linear model but fit other models such as the linear-quadratic or quadratic models of dose versus effect. The error (uncertainty) associated with these models is not an additive error but a geometric error where the observed value is either multiplied or divided by the associated error. If the associated error is large, then the confidence intervals can vary by an order of magnitude.

The issue in using risk for public health documents is the applicability of the existing data. Radiation risks derived from epidemiological studies are not necessarily precise because of the small sample size for a given disease state. Issues in applying the risks derived from these types of studies include population differences such as demographics, base line health of the populations (controls and experimental), and other lifestyles and how these compare to American styles. Another issue important to the risk assessment

not adequately addressed is the evaluation method used to adjust high dose and high dose rates to low dose and low dose rates. The term dose and dose rate effectiveness factor (DDREF) has been used to account for this difference but no clear determination of the true DDREF has been accepted. Typically a value of 2 is used, meaning the risk associated with low dose is 1/2 the risk from high dose/dose rate.

Issues related to proper determination of risk

Risk is defined as “*The potential for realization of unwanted, adverse consequences to human life, health, property, or the environment; estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event given that it has occurred.*” It follows from this definition that risk is a statistical concept, rather than a statement of public health. The evaluation of data in the development of risk numbers is important. For example, was the information on death certificates correct and verified by the appropriate agency? Important issues for this include cause of death, site of cancer, primary or secondary malignancy and related disease states that may have played a role in the onset of death.

There are some indications that sex and age are important in the induction of radiation-induced effects on humans. This is especially true for cancer estimates in the different sexes. The National Academy of Science BEIR V report (NRC 1990) assesses an uncertainty of 10% for sex related cancers. In the case of age related cancers, there may be different sensitivities based on age. Younger children may be more susceptible than older children based on the type of cancer. However, this sensitivity may change as the child ages especially if the time of disease onset is unknown. This is important if the evaluation is for less than a lifetime exposure. The evaluation over a lifetime is difficult in its own right.

The National Council on Radiation Protection and Measurement (NCRP), in their Report 136 on the LNT issues (NCRP 2001) reevaluated the existing data as it pertains to the dose-response of ionizing radiation and the health effects associated with exposures to ionizing radiation. Their evaluation focused on the mutagenic, clastogenic (chromosome-damaging), and carcinogenic effects of radiation ...As with other reviews by the NCRP, the council found no conclusive evidence to reject the LNT model for radiation dose response.” One result of these reviews, however, is that the NCRP stated that for cell systems receiving low-LET radiations the lowest dose at which a statistically significant increase of transformation over background has been demonstrated is 10 mGy. This is equivalent to a radiation dose of 1 rad, or for alpha radiation, a dose of about 20,000 mrem. In the case of animal studies, there is a variation however, in the dose response curves and the available information does not suffice to define the dose-response curve unambiguously for any neoplasm in the dose range below 0.5 Sv (50,000 mrem)...as stated on page 210 of the NCRP report. However, the NCRP also stated that other data on mice with regard to induction of neoplasms and life-shortening was not inconsistent with a linear response. Thus, there is uncertainty in the

response to the types of radiation, the endpoint under investigation, and the animal system being studied.

According to the NCRP, similar dose responses occur in humans as evidenced by many studies. However, many of these studies were the atomic bomb survivor studies where the doses and dose rates are much different to those parameters typically observed at hazardous waste sites. The NCRP states that in the bomb survivors, induction of leukemia appears to be linear-quadratic; however, studies may have missed the initial wave of leukemia as these studies began at least 5 years following the bombing. Overall, the induction of solid cancers has a LNT component as low as 50 mSv (5,000 mrem). Other radiation studies show a possible increase in fetal cancer following an exposure of 10 mGy and increased thyroid cancer following irradiation during childhood following a dose of 100 mSv (10,000 mrem) (NCRP, 2001).

What are the problems of using risk in public health documents?

Currently, the only unequivocally known health effect resulting from the exposure to radiation is the induction of cancer. However, data are beginning to appear in the literature associating exposures to cardiovascular diseases. The NCRP in 1993 reviewed the risks associated with radiation exposure and radiation induced cancers¹⁰. The NCRP identified 4 non-trivial concerns with the use of risks in the evaluation of radiation exposure. ATSDR has paraphrased these concerns as follows.

1. The risk varies with the selection of the appropriate risk-projection model.
2. The duration of exposure may vary from small periods of time to 50 years (workers) to 70 years (life time).
3. Coupled with the method whereby the dose is calculated can lead to wide variations in the resulting risk values. For example, are doses calculated for a short period of time or over the lifetime of the exposed individual. Furthermore, the extrapolation from high dose, high dose rate to low dose, low dose rate becomes important over these various time frames.
4. Concomitant with the problems associated with the dose/dose rate issues, is the adjustment for ethnicity, population dynamics, and other significant differences among the populations irradiated. For example, the Japanese population of the 1940s and the United States population of the latter half of the 20th century.

The NCRP also recommends that other factors contributing to this detriment should be considered. These factors include genetic effects, teratogenic effects and, length of loss of life.

Appendix 6: EPA Soil Screening Guidance for Radionuclides

Derivation of the Risk-Based Soil Screening Levels (Pu 239 in Soil)

The EPA has promulgated the use of Soil Screening Levels (SSLs; http://risk.lsd.ornl.gov/rad_start.shtml; Table 3) as “... **guidance is intended to be used to screen out areas of sites, exposure pathways, or chemicals of concern from further consideration, assuming certain conditions are present, or to determine that further study is warranted at a site.**” These SSLs are risk-based concentrations that may be used to exclude areas or contaminants from further evaluation, or conversely identify areas or contaminants that require additional evaluation.

Using standard EPA default assumptions for intake and exposure conditions and an excess cancer risk of one in million, the SSL for Pu 239 in soil is 2.9 pCi/g.¹⁸ This SSL is based on ingestion of soil that is age adjusted over a period of 30 years. More importantly, this SSL is based on an average soil concentration over an entire residential lot of ½ acre (EPA 2002). Use of the SSL (or the previously referenced PRG) as a screening value for single point, maximum value samples is inappropriate. Correct use of these risk-based SSLs requires that soil samples be composited or averaged over an entire exposure area (1/2 acre in this evaluation).

None of the available sampling data for either Pu 239 or gross alpha have been averaged over an area that is appropriate for comparison to the SSL (or PRG) concentrations. However, as all of the currently available, maximum point values are below the SSL of 2.9 pCi/g, it is very unlikely that any potential exposure areas will contain an average Pu 239 soil concentration above the SSL.

¹⁸ SSLs for inhalation, food ingestion, and external exposure are higher than the soil ingestion SSL (4,700 pCi/g, 8.1 pCi/g, and 560 pCi/g, respectively). The SSL is the same as the previously referenced PRG of 2.5 pCi/g. The difference in the SSL value of 2.9 pCi/g is due to changes in the Pu 239 dose conversion factors.

Usage and Limitations:

- SSLs are not national cleanup standards.
- Radionuclide SSLs are based on a target risk of one-in-a-million (10^{-6}), or, for the ground water migration pathway, a maximum contaminant level (MCL), where available.
- Although the application of SSLs during site investigations is not mandatory at sites being addressed by CERCLA or RCRA, EPA recommends the use of SSLs as a tool to facilitate prompt identification of radionuclides and exposure areas of concern.
- In addition, this guidance presents methodologies to address the leaching of radionuclides through soil to an underlying potable aquifer. This pathway should also be addressed in the development of PRGs.
- The Soil Screening Guidance is a tool for screening at National Priorities List (NPL) sites.
- Some NPL sites will not meet all the conditions necessary for use of this tool; consequently, EPA does not expect this tool to be applicable for all NPL sites.
- The guidance is intended to be used to screen out areas of sites, exposure pathways, or chemicals of concern from further consideration, assuming certain conditions are present, or to determine that further study is warranted at a site.
- Generally, areas of a site which fall below the screening levels may be eliminated from further assessment. Areas above the screening levels generally warrant further evaluation.
- The levels should not be interpreted to represent cleanup standards for a site, and concentrations in soil above screening levels do NOT automatically designate a site as dirty.
- SSLs do not supersede existing federal or state ARARs and use of the guidance is not legally binding.
- An ecological assessment should also be performed as part of the RI/FS to evaluate potential risks to ecological receptors.
- Although SSLs are "risk-based," they do not eliminate the need to conduct a site-specific risk assessment for those areas identified as needing further investigation.
- Exposure Pathways are as follows:
 - Direct ingestion of soil
 - Inhalation of fugitive dusts
 - External radiation exposure from photon-emitting radionuclides in soil
 - Ingestion of homegrown produce that has been contaminated via plant uptake
 - Ingestion of contaminated ground water caused by migration of radionuclides through soil to an underlying potable aquifer

Table 3. Usage and Limitations of risk-based Soil Screening Levels (SSLs); from http://risk.lsd.ornl.gov/rad_start.shtml (EPA 2002).

<http://risk.lsd.ornl.gov/rad-ssg/radssl1.shtml>

SELECTION:

Your **Analytes** are:

Pu-239

Your **Pathways** are

Ingestion of Soil

Ingestion of Produce

Inhalation of Fugitive Dust

Default Parameters

Each pathway you have selected is given below along with the applicable Equations and its associated Default Parameters. For each equation, the default values will be used unless you enter a different value.

Ingestion

Ingestion of Radionuclides in Soil - Age Adjusted

$$SSL_{DC} = \frac{TR * t * \lambda}{SF_s * IR_s * 10^{-3} * EF * ED * (1 - e^{-\lambda t})}$$

$$IR_s = \frac{IR_{soil\&age\ 1-6} * ED_{age\ 1-6} + IR_{soil\&age\ 7-31} * ED_{age\ 7-31}}{ED}$$

1.0E-6

TR (target risk) unitless

350

EF (exposure frequency) d/yr

100

IR_a (adult ingestion rate) mg/d

200

IR_c (child ingestion rate) mg/d

24

ED_a (adult exposure duration) yr

6

ED_c (child exposure duration) yr

30

ED (exposure duration) yr

30

t (time of exposure) yr

120

IR_s (soil ingestion rate) mg/d

NOTES:

1. Screening level equations have been modified to account for radioactive decay.
2. SF_s=Oral Slope Factor for Soil Ingestion. Radionuclide-specific.*
3. λ = Decay constant (0.693/half-life) yr⁻¹. Radionuclide-specific.

4. 10^{-3} = conversion factor (g/mg)

Ingestion of Radionuclides in Soil - Adult Only

$$SSL_{DC} = \frac{TR * t * \lambda}{SF_s * IR_s * 10^{-3} * EF * ED * (1 - e^{-\lambda t})}$$

1.0E-6 TR (target risk) unitless

250 EF (exposure frequency) d/yr

25 ED (exposure duration) yr

50 IR_s (soil ingestion rate) mg/d

25 t (time of exposure) yr

NOTES:

1. Screening level equations have been modified to account for radioactive decay.
2. SF_s = Oral Slope Factor for Soil Ingestion. Radionuclide-specific.*
3. **Use this pathway for adult-only situations (i.e. worker, etc.)**
4. λ = Decay constant (0.693/half-life) yr^{-1} . Radionuclide-specific.
5. 10^{-3} = conversion factor (g/mg)

Inhalation of Fugitive Dusts

Inhalation of Fugitive Dusts - Particulate Emission Factor

$$PEF = Q/C * \frac{3,600}{0.036 * (1 - V) * (U_m / U_t)^3 * F(x)}$$

San Francisco (II) City ([Climatic Zone](#))

0.5 Surface (acres)

89.51 Q/C (inverse of the mean conc. at the center of a 0.5-acre-square source) $g/m^2 \cdot s$ per kg/m^3

0.5 V (fraction of vegetative cover) unitless

3.89 U_m (mean annual windspeed) m/s

11.32 U_t (equivalent threshold value of windspeed at 7m) m/s

0.0391 F(x) (function dependent on U_m/U_t) unitless

NOTES:

1. PEF (particulate emission factor) m³/kg. Default is 1.32x10⁹
2. The Surface Area and City/Climate Zone are used to look up a Q/C. Q/C is the inverse of mean concentration at center of a 0.5 acre-square source (g/m²-s per kg/m³). Pick the city with the most similar climatic conditions ([map](#)).
3. The F(x) function is derived using Cowherd et al. (1985)

Inhalation of Radionuclides in Fugitive Dusts

$$SSL_{DC} = \frac{TR * t * \lambda}{SF_i * IR_i * \left(\frac{1}{PEF}\right) * 10^3 * EF * ED * [ET_o + (ET_i * DF_i)] * (1 - e^{-\lambda t})}$$

1.0E-6

TR (target risk) unitless

20

IR_i (inhalation rate) m³/d

0.073

ET_o (outdoor exposure time fraction) unitless

0.683

ET_i (indoor exposure time fraction) unitless

350

EF (exposure frequency) d/yr

30

ED (exposure duration) yr

0.4

DF_i (indoor dilution factor) unitless

30

t (time of exposure) yr

NOTES:

1. Screening level equations have been modified to account for radioactive decay.
2. SF_i (inhalation slope factor) (pCi⁻¹) - chemical specific.*
3. PEF (particulate emission factor) m³/kg. Default is 1.32x10⁹.
4. λ = Decay constant (0.693/half-life) yr⁻¹. Radionuclide-specific.
5. 10³ = conversion factor (g/kg)

Ingestion of Produce

Ingestion of Homegrown Produce in Soil

$$SSL_{DC} = \frac{TR * t * \lambda}{SF_p * (IR_{vf} + IR_{lv}) * 10^3 * TF_p * CPF * ED * (1 - e^{-\lambda t})}$$

1.0E-6

TR (target risk) unitless

42.7

IR_{vf} (vegetable and fruit ingestion rate) kg/year

4.66

IR_{lv} (leafy vegetables ingestion rate) kg/year

0.5

CPF (contaminated plant fraction from the site) unitless

30

ED (exposure duration) yr

30

t (time of exposure) yr

NOTES:

1. Screening level equations have been modified to account for radioactive decay.
2. SF_p (produce ingestion slope factor) (pCi)⁻¹ - radionuclide-specific.*
3. TF_p (soil-to-plant transfer factor) (pCi/g plant per pCi/g soil).
4. λ = Decay constant (0.693/half-life) yr⁻¹. Radionuclide-specific.
5. 10³ = conversion factor (g/kg)

*Slope factors are taken from the updated [Health Effects Assessment Summary Tables \(HEAST\): \(Radionuclide Carcinogenicity Slope Factors\)](#), in units of picocuries. The curie (Ci), the customary unit of activity, is equal to 3.7 x 10¹⁰ nuclear transformations per second. 1 picocurie (pCi) = 10⁻¹² Ci. The International System (SI) unit of activity is the becquerel (1 Bq = 1 nuclear transformation per second). If required, screening levels can be converted into SI units.

Please select desired units option:

pCi/g

Bq/g

You must select one of the following output options

View on Screen

 Tab delimited file

 Comma delimited file

RETRIEVE

clear selection

[[EPA Home](#) | [OSWER Home](#) | [Superfund Home](#)]
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URL: <http://risk.lsd.ornl.gov/radssl1.cgi>
This page was last updated on: October 10, 2000
Site Maintained by: U.S. EPA, Office of Emergency and Remedial Response
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Equation Values for Ingestion of Soil

Age-adjusted Parameter	Value	Adult-only Parameter	Value
Target Risk (unitless)	1.0E-6	Target Risk (unitless)	1.0E-6
Adult Exposure Duration (yr)	24	Exposure Duration (yr)	25
Child Exposure Duration (yr)	6		
Exposure Frequency (day/yr)	350	Exposure Frequency (day/yr)	250
Adult Intake Rate (mg/day)	100		
Child Intake Rate (mg/day)	200		
Age-adjusted Intake Rate (mg/day)	120	Intake Rate (mg/day)	50
Time of Exposure (yr)	30	Time of Exposure (yr)	25

Decay-Corrected Screening Levels for Ingestion of Soil

Analyte	Soil Ingestion Slope Factor (risk/pCi)	Decay Constant λ (yr ⁻¹)	Half-life (yr)	SSL (Age- adjusted) (pCi/g)	SSL (Adult) (pCi/g)	SSL (Age- adjusted) (mg/kg)	SSL (Adult) (mg/kg)
Pu-239 decaychain	2.8E-10	2.9E-05	2.4E+04	2.9E+00	1.2E+01	4.6E-05	1.9E-04

Equation Values for Ingestion of Produce

Parameter	Value
Target Risk (unitless)	1.0E-6
Exposure Duration (yr)	30
Contaminated Plant Fraction from the site (unitless)	0.5
Vegetable and Fruit Ingestion Rate (kg/yr)	42.7
Leafy Vegetable Ingestion Rate (kg/yr)	4.66
Time of Exposure (yr)	30

Decay-Corrected Screening Levels for Ingestion of Produce

Analyte	Food Ingestion Slope Factor (risk/pCi)	Decay Constant λ (yr ⁻¹)	Halflife (yr)	Soil-to-plant Transfer Factor (pCi/g plant/pCi/g soil)	SSL (pCi/g)	SSL (mg/kg)
Pu-239 decaychain	1.7E-10	2.9E-05	2.4E+04	1.0E-03	8.1E+00	1.3E-04

Equation Values for Inhalation of Fugitive Dust

Particulate Emission Factor Parameter	Value	Equation Parameter	Value
Surface Area (acres)	0.5	Target Risk (unitless)	1.0E-6
City (climate zone)	SanFrancisco(II)	Exposure Duration (yr)	30
Q/C (g/m ² -s per kg/m ³)	89.51	Exposure Frequency (day/yr)	350
Fraction of vegetative cover (unitless)	0.5	Inhalation Rate (m ³ /day)	20
Mean annual windspeed (m/s)	3.89	Outdoor Exposure Time Fraction (unitless)	0.073
Equivalent threshold value of windspeed at 7m (m/s)	11.32	Indoor Exposure Time Fraction (unitless)	0.683
Function dependent on U_m/U_t (unitless)	0.0391	Indoor Dilution Factor (unitless)	0.4
		Time of Exposure (yr)	30

Decay-Corrected Screening Levels for Inhalation of Fugitive Dust

Analyte	Inhalation Slope Factor (risk/pCi)	Decay Constant λ (yr ⁻¹)	Half-life (yr)	Particulate Emission Factor (m ³ /kg)	SSL (pCi/g)	SSL (mg/kg)
Pu-239 decaychain	3.3E-08	2.9E-05	2.4E+04	1.1E+10	4.7E+03	7.5E-02