AN ABSTRACT OF THE THESIS OF

Manuel P. Williams for the degree of Master of Science in Radiation Health Physics presented on June 10 2011.

Title: How Clean is Coal: Coal Power Plant Ash Pond Regulations Compared To Nuclear Reactor Decommissioning Standards

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Coal power is the prominent source of energy in the United States (U.S.) and around the world. The byproducts of coal power contain many of the same radioactive nuclides that are found in the local environment just in higher concentrations. With so much of this ash being stockpiled, the amount of radioactive material in one location can be staggering.

Currently, U.S. Environmental Protection Agency (EPA) regulations covering disposal of coal ash are focused on protection of the environment and the general public from the risks associated with heavy metals like mercury and arsenic, but not specifically for radionuclides. However, in the case of decommissioning of nuclear power facilities, both the EPA and U.S. Nuclear Regulatory Commission (NRC) regulations for environmental protection are quite stringent. Comparisons of the risk basis for the regulatory oversight of residual radiation from the two different sources of power are needed to bring the radiation levels into context.

Utilizing the software package RESRAD simulations of the annual radiation dose were made to hypothetical members of the general public residing in an area contaminated by the coal ash residue from two coal-fired power facilities. The first is the Kingston facility operated by the Tennessee Valley Authority (TVA) and the second is

Portland General Electric’s (PGE, Boardman coal-fired plant. The methodology used in this assessment is the state of practice followed by the nuclear power industry as it decommissions its facilities. Radionuclide collected and made publically available from the TVA Kingston spill was used along with soil data from the USDA for the two locations. The coal ash quantities, quality, and type were obtained from data TVA and applied to the PGE site.

Results from the simulation suggested elevated radiation levels to occupants residing on either site. At the TVA Kingston site, the maximum radiation dose was more than 100 mrem/y or 4 times greater than what would acceptable from a nuclear facility and over the EPA radiation to the general public levels of 100 mrem/y. The maximum dose projected for the PGE site was more than 200 mrem/y. The difference between the two sites was due to soil and environmental erosion coefficients.

How Clean is Coal: Coal Power Plant Ash Pond Regulations Compared To Nuclear Reactor Decommissioning Standards

By
Manuel P. Williams

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APPROVED:

Major Professor, representing Radiation Health Physics

Head of Department of Nuclear Engineering and Radiation Health Physics

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Manuel P. Williams, Author

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Introduction

According to an energy audit conducted by British Petroleum (BP) coal power is the prominent source of energy in the U.S. and around the world. Coal contains natural radioactive elements and when it is burned, the remaining constituents are collectively called coal fly ash. This ash is stockpiled in ponds for long-term storage. The amount of radioactive material that can reside at these large ash ponds can be staggering when looking at the compositional parts that make up the coal ash. The EPA currently regulates the heavy metal contamination from coal ash, but there is currently no monitoring regulation for the radiological contamination in the ash or the surrounding soil or water. Comparisons of the risks for the regulatory oversight of residual radiation from the two different sources of power, coal and nuclear, are needed to bring the radiation levels and regulations into context.

The purpose of this research was to conduct a dose analysis for two coal ashe storage sites: Tennessee Valley Authority (TVA) Kingston and Portland General Electric (PGE) Boardman. This methodology is the state of practice followed by the nuclear power industry as it decommissions its facilities.

Literary Review

Coal Power

Coal Power is an integral part of the global economy and national power supply. The use of coal to generate heat can be traced as far back as 3000 B.C. in the funeral pyes of England. Coal has since been used to generate heat for warming homes, forges, and power generation. According to the United States Energy Information Administration, the world coal consumption was 6,743,786,000 short tons in 2006 (Freme, 2010). That amount of coal would cover approximately 56,198 football fields 100 feet deep with coal or cover the state of Rhode Island 9.26 feet deep with coal.

In 2009, 29.4% of the world's energy was generated by coal power production. China dominates coal consumption at 46.9% of the world's coal, while the U.S. uses 15.2%. In the next twenty years, the demand is expected to increase by 48% ("BP Statistical," 2010). Currently, the U.S. obtains 43% of its total energy from coal power and 20% from the nuclear industry.

Figure 1 shows the amount of coal production and consumption in million tons of oil equivalents. Most continents' coal usage has grown or shrunk minimally, while Asia has had a mass increase in the amount of coal produced and consumed. The data used to create Figure 1 is taken from the BP statistical guide released by BP in 2010.

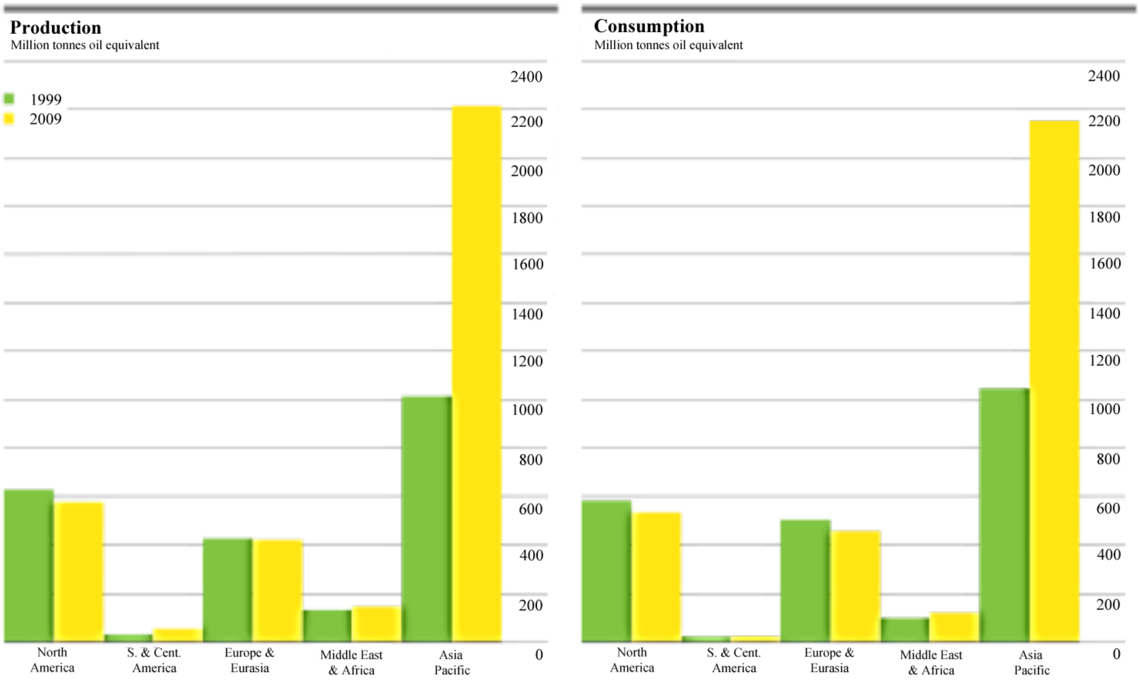


Figure 1: Coal Production and Consumption for 1999 and 2009

Coal Composition and Characteristics

Coal is a blackish combustible sedimentary rock. It is called a fossil fuel because of how it was created. Millions of years ago, there were massive swamps that covered a moderate portion of the U.S. The plant material that came from those swamps is the main component of coal. Over the millions of years that passed, more and more sediment layered on top of the areas that were once swamps. The weight of the sediment compressed the decaying material until enough weight and time led to the formation of coal.

Coal is graded based on the heat value and the thickness of the coal layer. The grading system ranks coal from lowest to greatest heat value in the following order: lignite, sub-bituminous, bituminous, and anthracite. The higher the rank, the harder and brighter the coal becomes. The heat value is defined by how much heat is given off when burning the coal. If the coal receives enough pressure and heat, the coal will become graphite, almost pure carbon sheets, which are not easily ignitable. With enough pressure and heat, the graphite can become diamonds.

Coal beds in the eastern U.S. are generally less than 15 feet thick, while some of the deposits in the West can be over 65 feet thick. Coal is by far the most abundant fossil fuel in the U.S. High sulfur coal was produced in areas that were covered by salt water, while low sulfur coal was developed in areas primarily covered by fresh water. The incombustible minerals in the coal are what form the coal ash after the coal is burned.

Coal Ash Composition and Characteristics

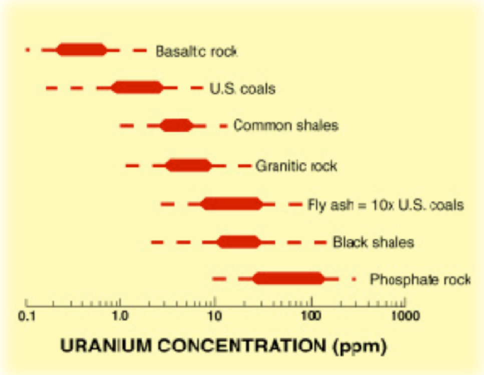


Figure 2: Typical range of uranium concentration in coal, fly ash, and a variety of common rocks.

Coal ash is a byproduct of the incineration process of coal power production. The radionuclides reside in the residue ash that is left behind once the coal is incinerated. Figure 2 shows the uranium concentration in coal ash, sometimes called fly ash, in comparison to coal and other common rocks and was obtained from the USGS Fact Sheet FS-163-97. In a report by Alex Gabbard for the ORNL Review it has been calculated that in 1982, 2.6 kCi of radiation was released into the environment, via exhaust and coal ash from coal power production in the U.S. The Three Mile Island accident, which released radioactive noble gasses into the atmosphere, released a mere 0.017 kCi in comparison (Gabbard, 1993).

About 10% of the original mass of coal remains as ash after it has been processed. The coal ash has three primordial radionuclides: uranium, thorium, and potassium, along with radium and other progeny radionuclides ("Coal ash," 2010). According to the EPA, coal ash has an average radiation level of 3.5 to 4.6 pCi/g, common soil has an average radiation level of 1 to 4 pCi/g. This ash is stored in dry landfills near the coal power plant. Each landfill can be hundreds of acres in area and up to 30 feet deep. The coal ash has different characteristics based on where the coal originates. West Coast coal ash has a tendency to have a lower pH when compared to eastern bituminous coal ash. The pH of the coal ash affects the solubility and hydraulic conductivity- the two ways water passes though and transports a material such as a radionuclide. Coal ash has a density around 1.6 g/cm^3 (Openshaw, Miller, Bolch, Bloomquist, 1992).

EPA Radiological Standards for Coal

Currently, the EPA does not have any regulations regarding the radionuclide content of coal ash. However, there are two different proposals in progress that could affect coal ash landfills. Both proposals would operate under the Resource Conservation and Recovery Act. The first proposal would classify coal ash as “special waste”, phasing out wet storage ponds in preference to landfills. The second proposal would require a composite liner between the bed soil and the coal ash to minimize the amount of leakage into local water supplies. These proposals were set into motion as a result of the TVA Kingston coal ash spill that occurred in December 2008 (Bassett, 2010).

NRC Decommissioning Regulations

The regulation pertaining to nuclear power plant decommission can be found in 10 CFR 20.1401-.1404. The criteria for the site specify that "the residual radioactivity that is distinguishable from background radiation results in a total effective dose equivalent (TEDE), to an average member of the critical group that does not exceed 25 mrem (0.25 mSv) per year including that from ground water sources". When the company is calculating the TEDE, the company must ensure that the 25 mrem per year, above and beyond background levels, is not exceeded in the first 1,000 years after the decommissioning of the site. In comparison, the occupational dose limit for a radiation worker is 5,000 mrem and 500 mrem for the general public (NRC, 2011). In 2011, the NRC released a fact sheet on the biological of radiation and stated that the average background radiation dose to members of the public in the U.S. from natural sources is 310 mrem/y. Figure 3 represents the demolition of the cooling towers at PGE Trojan nuclear power plant in Rainer Oregon. Demolishing the cooling towers is one of the steps in the preparation of returning the area to the general public for unrestricted use.

Figure 3: PGE Trojan cooling tower demolition.

TVA Kingston Spill

Figure 4: Satellite photo of TVA Kingston Spill.

In December 2008, there was a critical failure of a levee that held hundreds of tons of coal ash from the local environment. The accident occurred at the Kingston Power Plant that is operated by the TVA. The Kingston Coal plant is located near Kingston, Tennessee on the Emory river. When the levee failed, coal ash flowed into the local ecosystem. The EPA has a list of sites that it considers to be high hazard and that need remediation. At the time of the incident, the Kingston site was not on that list. The levee failure released 5.4 million cubic yards of coal ash into the local ecosystem. The coal ash went one of two places, either to the north into some farmlands or east into the Emory River and riparian zone.

TVA Kingston Site Rehabilitation

The cleanup of the Kingston spill was extensive. TVA purchased most of the land that was affected by the spill, relocated residences, and dredged the river to remove coal ash deposits. The TVA began with large land moving equipment to scrape up as much of the coal ash as possible. The recovered ash was shipped to a landfill in Alabama. Floating booms were placed in the river to collect the floating cenospheres, ceramic spheres that are created during the coal burning process, and an underwater dam, designed to stop settled ash from moving downstream, was partially built before the spill (Dewan, 2008).

TVA also released plans for the remediation of the coal ash ponds at Kingston and several other coal plants.

During the cleanup, TVA purchased many of the houses and land that were affected by the spill. TVA has also spent a large amount of time dredging the river to remove any coal ash sediment that may have washed down river. After two years of clean up, only half of the coal ash has been recovered. TVA is in the process of converting all of its wet storage coal ash ponds into dry storage landfill by 2020. The TVA drafted the corrective action plan, which informed both the public and the EPA of the actions that TVA would be taking to rehabilitate the area affected by the Kingston spill.

The current Kingston coal ash ponds have a layer of clay at the base about 15 feet deep. The coal ash is then stacked on top of that anywhere from 15 feet to 95 feet deep. This amounts to more than 525 million gallons of ash slurry. The coal ash has a density around 1.6 g/cm^3.

Soil Types and Locations

There are many types of soil in the U.S. and around the world and they all have different characteristics that change how a radionuclide will move from the coal ash and into the local environment. It is important to take these variables into consideration when looking how the radiation will inevitably reach the occupants.

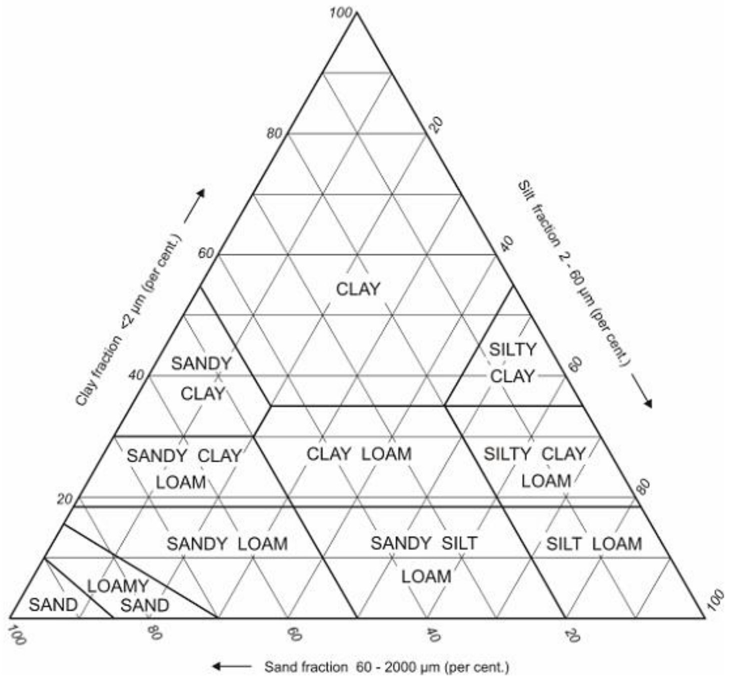


Figure 5: Soil Texture Triangle.

Soil can be described based on the relative proportion of sand, silt, and clay. Figure 5 shows the types of soil in relation to their relative composition was drawn by R. Burton.

Clay is a very fine granule mineral and has the smallest size of the three soil constituents. Silt is the middle-sized granule mineral of the group and is grittier than clay but still finer than sand. Sand has the largest aggregate of the group. The size of the particles is an integral part in the hydraulic conductivity of the soil. The smaller the particles that comprise the soil, the less permeable it is. This is due to how tightly the particles are packed together. Smaller particles have smaller microscopic gaps, which are not conducive to water movement through the soil. Greater water movement is created when there is vast amount of large contiguous space in between minerals in the matrix of the soil's structure. Clay has a dry density of 1.2 g/cm^3, while sandy loam has a density of 1.44 g/cm^3.

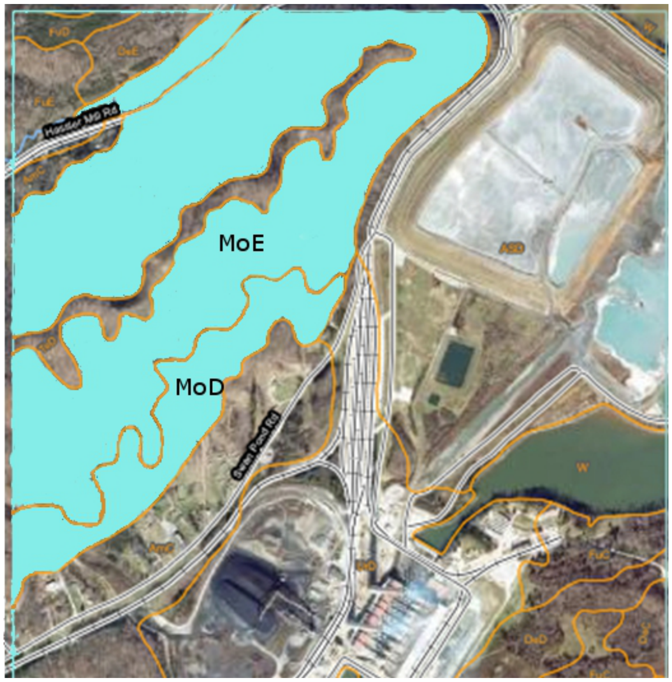


Figure 6: Soil Map TVA's Kingston Plant

The soil located near the TVA Kingston site is considered a silt loam with a sand, silt, and clay ratio of approximately 29:54:17, identified as silt loam on figure 6 by the designation of sections MoD and MoE designated by the light blue areas. The orange lines on the map identify a change in soil types. The saturated hydraulic conductivity for this type of silt loam is between 4 to 14 µm/s. The soil is very stable against wind erosion with an estimated two tons of soil per acre per year or .0014 meters per year being removed. There is an average rainfall of 48 to 61 inches per year (United States Department of Agriculture, 2011).

The soil located near the PGE Boardman site is considered a sandy loam with a sand, silt, and clay ratio of approximately 65:27:8 identified as sandy loam on Figure 7 by the designation of section 54B, the majority the figure. At depths over 15 to 30 inches, the soil composition contains a higher percentage of silt than the surface soil. The saturated hydraulic conductivity for this type of sandy loam is between 14 to 42 µm/s with the sand dune being as high as 141 µm/s. The soil is less than moderately stable against wind erosion with an estimated 5 tons of soil per acre per year or 0.0035 meters per year being removed due to wind and water erosion. There is an average rainfall of 8 to 9 inches per year. The soil maps and characteristics were obtained utilizing the Web Soil Survey (WSS) web application located on the USDA website (United States Department of Agriculture, 2011).

Figure 7: Soil Map PGE's Boardman Plant

US Food Intake

As part of the process to evaluate radiation exposure to the general public, it is important to examine all pathways of exposure. one aspect of this effect is examining the consumption of contaminated food. As of 2003, the USDA tabulated the amount of foods eaten by the average U.S. citizen. There will be variables to the local population, but as a general rule of thumb, these numbers will be close for any population average in the U.S. Coastal regions will see an increase in the consumption of fish, while the interior will see an increase in vegetable intake like corn. Table 1 identifies the values of per capita consumption of food and beverages in 2003 (Farah and Buzby, 2005).

Table 1: Food Consumption per Capita for 2003 in US

Per Capita Consumption for 2003

Commodity	Measure	Commodity	Measure
Fats and Oils	86 lbs.	Dairy	594 lbs.
Grains	194 lbs.	Vegetables	418 lbs.
Sugar and sweeteners	142 lbs.	Meat, Eggs, and Nuts	242 lbs.
Fruits	275 lbs.	Beverage w/o dairy	117 gallons
Total		=1,951 lbs of food 117 gallons of fluid	

Application of Data

Utilizing the data from the Kingston spill, the TEDE to a hypothetical individual living in the vicinity of a coal ash pond will be compared to the decommissioning standards for a nuclear power plant. RESRAD, a software package used to estimate the TEDE to an individual living in an area with contamination, will be used to calculate the TEDE from the releases from stabilized coal ash ponds at the TVA and PGE sites. Each site has differing geological and coal compositions and the average values for these settings will be used. These findings could easily be utilized for any coal plant as long as all of the variables are accounted for (TVA, 2009). The key variables for this experiment are the radionuclides concentrations, size of the covered source, erosion rate, precipitation rate, wind speed, soil characteristics, and food intake,

Material and Methods

Introduction

With coal an integral part of power consumption in the U.S., we need to be concerned with the byproducts of this energy source. The TVA Kingston site was an eye-opening event that shed much needed light onto the coal power industry. Utilizing the data collected from the Kingston spill, it can be applied to other locations around the U.S. and identify how the storage of coal ash would behave in different environments if the area were released for unrestricted use by the general public.

TVA Kingston Site

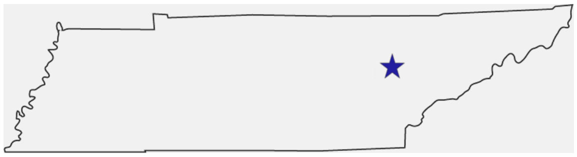
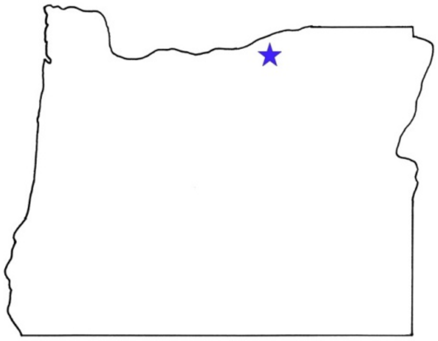


Figure 8: Roane county in Tennessee

The TVA Kingston site is located in Roane County in Tennessee at 35.91° N Lat., 84.51° W Lon., identified by the blue star on Figure 8. The site is positioned so that the Emory river runs along the north and east boundaries of the coal ash ponds. There are earthen levees separating the coal ash from the river and riparian zones. In a TVA press release, currently Kingston utilized a hybrid wet/dry ash storage solution prior to the spill but is now in the process of converting to a 100% dry solution.

PGE Boardman Site



The PGE Boardman site is located in Morrow County in Oregon at 45.7° N Lat., 119.8° W Lon., identified by the blue star on Figure 9. The site is located on the northern bank of an unnamed, manmade lake. EPA water tests have shown the lake to have higher than allowed for heavy metals and contaminates. According to the PGE Boardman website, the site utilizes dry ash storage, a process of moving and storing the coal ash as a dry product.

Sampling of data

The data used for this analysis were gathered from two main sources. Coal ash data were collected and analyzed based on data available from the Kingston coal ash spill on December 2008. The soil, environmental, and food intake parameters were collected from the U.S. Department of Agriculture.

RESRAD Software

The dose calculations were accomplished by using RESRAD software version 6.5 (Argonne National Laboratory, Chicago, Illinois). The RESRAD software is used to calculate the TEDE in different scenarios. Different exposure scenarios are considered, with the code calculating the residual radioactivity left in the soil after specified periods of time and the dose delivered to a reference individual. RESRAD has the capability of predicting the dose to a reference individual for any time up to 100,000 years and break the contributing dose elements into the different pathways. RESRAD identifies the reference individual as being between 20-30 years of age, weighing 70 kilograms is 170 cm in height and lives in a climate between 10 and 20 degrees Celsius. The software can also be configured to calculated doses for children, to ensure that regulatory decisions that are made regarding the site are made with the best accuracy for the situation at hand.

In this work, the dose to the public is calculated for 1,000 years after the site would be released for unrestricted use. Reports can be generated to show the dose received from each radionuclide or from all radionuclides combined.

Radionuclide data

Since data about the coal ash at PGE Boardman is not available, the Kingston data was used. To compare the two sites, geographical and environmental variables are used from each site based on EPA information to give the best comparison between the two sites and not necessarily the correlating ash ponds.

Exposure Pathways

The two main pathways that dose is calculated is water dependent and independent.

For water dependent pathways, the system only takes into account the dose that is related to the water from contaminated well or surface water. For water dependent plants meat and milk, the dose is derived from water used during irrigation and livestock feed. This data is also used for deriving the dose from drinking water and fish ingestion. possible pathways includes: drinking water, fish, radon, plants, meat, and milk.

For water independent doses, the system excludes the dose arriving from contaminated water sources but still accounts for the leaching of the radionuclides from the soil. For water independent plant meat and milk pathways, the water contribution is not counted towards the calculated dose. Water independent pathways also take into account soil ingestion. possible pathways include: external, inhalation, radon, plants, meat, milk, and soil ingestion.

Table 2 is a compiled list of the RESRAD input variables that were used for both the Kingston and Boardman sites. Many of the variables are the same for both sites. The key differences are highlighted. The listed variables have been collected from both the TVA coal ash data and several locations on the USDA website.

Table 2: Variables used in RESRAD for TVA Kingston and PGE Boardman profiles

Variables	TVA Kingston	PGE Boardman
Soil Concentration		
Potassium-40	27.20 pCi/g	27.20 pCi/g
Radium-226	5.85 pCi/g	5.85 pCi/g
Radium-228	4.24 pCi/g	4.24 pCi/g
Thallium-208	3.40 pCi/g	3.40 pCi/g
Thorium-228	0.78 pCi/g	0.78 pCi/g
Thorium-230	2.21 pCi/g	2.21 pCi/g
Thorium-232	1.00 pCi/g	1.00 pCi/g
Uranium-234	1.78 pCi/g	1.78 pCi/g
Uranium-235	0.12 pCi/g	0.12 pCi/g
Uranium-238	1.76 pCi/g	1.76 pCi/g
Calculation times	1,10,100,1000 Y	1,10,100,1000 Y
Contaminated Zone		
Area of contaminated zone	33935 m^2	33935 m^2
Thickness of contaminated zone	5.57 m	5.57 m
Length parallel to aquifer flow	1143 m	1143 m
Penetration water table	No	No
Contaminated fraction below	0	0
Cover and contaminated zone		
Hydrological Data		
Cover depth	1 m	1 m
Density of cover material	1.44 g/cm^3	1.44g/cm^3
Cover erosion rate	0.0014 m/y	0.0035 m/y
Density of contaminated zone	1.6 g/cm^3	1.6 g/cm^3
Contaminated zone erosion rate	0.001 m/y	0.001 m/y
Contaminated zone total porosity	0.4	0.4
Contaminated zone field capacity	0.2	0.2
Contaminated zone hydraulic conductivity	0.31536 m/y	0.31536 m/y
Contaminated zone b parameter	5.3	5.3
Evapotranspiration coefficient	0.3	0.5
Wind Speed	1.78816 m/s	5.36448 m/s
Precipitation	1.397 m/y	.3048 m/y
Irrigation	0.2	0.2
Irrigation Mode	overhead	overhead

Runoff Coefficient	0.1	0.1
Watershed area for nearby stream or pond	1875000	1875000
Accuracy for water/soil computations	0.01	0.01
Saturated zone hydrological data		
Density of saturated zone	1.2	1.44
Saturated Zone total porosity	0.1	0.2
Saturated Zone effective porosity	0.05	0.2
Saturated Zone field capacity	0.4	0.2
Saturated Zone hydraulic conductivity	284.01 m/y	883.59 m/y
Saturated Zone hydraulic gradient	0.02	0.02
Saturated Zone b parameter	5.3	5.3
Water table drop rate	0.01	0.005
Well pump intake depth	25	25
Model for water transport parameters		
Well pumping rate	250	250
Uncontaminated unsaturated zone		
Unsaturated zones	0	0
Occupancy, inhalation, and external gamma		
Inhalation rate	8,400	8,400
Mass loading for inhalation	0.0001	0.0001
exposure duration	30	30
Indoor dust filtration factor	0.6	0.6
External gamma shielding factor	0.7	0.7
Indoor time fraction	0.5	0.5
Outdoor time fraction	0.5	0.5
Shape of contaminated zone	Circular	Circular
Ingestion: dietary		
Fruit, Vegetable, and grain consumption	312.9 kg/y	312.9 kg/y
Leafy vegetable consumption	0	0
Milk consumption	269.4 kg/y	269.4 kg/y
Meat and Poultry consumption	109.8 kg/y	109.8 kg/y
Fish consumption	0	0
Other seafood consumption	0	0
Soil ingestion	16.6 g/y	16.6 g/y
Drinking water intake	442.9 L/y	442.9 L/y
Rest of settings	RESRAD Default	RESRAD default

Results

The results of the analysis described in the Material and Methods section are presented below. The dose derived from the initial radionuclide and its progeny are lumped under the nuclide which heads of a decay chain.

Kingston Spill Site Results

Results presented are based on radionuclide data publically provided for the soil and coal ash from the TVA Kingston spill. Radionuclide values for the PGE site likely to be somewhat different based on the type and origin of the coal that is used to produce the ash.

Figure 10 illustrates the dose received for each of the radionuclides over all pathways of possible exposure to the reference individual. There are two main spikes in the dose over the 1,000 year period of analysis. The first spike from K-40 and the second originated primarily from Ra-226. The initial increase of K-40 is due to the potassium migrating to the water table. The fall in dose from K-40 is due to the potassium being flushed from the contaminated zone and diluted in the main water supply. The second spike (at approximately 700 years post closure) is due to erosion of the clean soil cap, exposing the contaminated soil to the atmosphere. This erosion allows for increased Ra-226 migration and release of progeny like Rn-222. The decrease in dose from Ra-226 exposure is due to the source being eroded away at the rate of .001 m/yr.

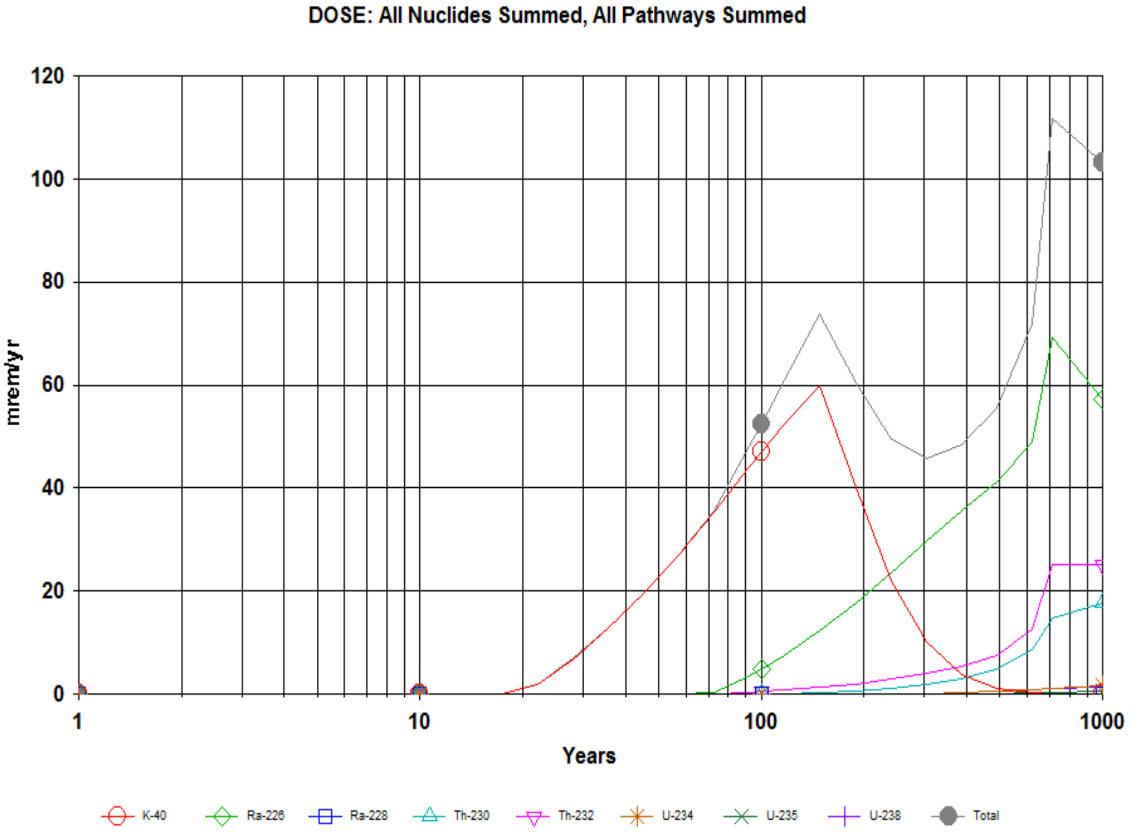


Figure 10: Results of the RESRAD run for the TVA Kingston site.

Figure 11 shows the radiation dose received for each exposure pathway from all radionuclides at the TVA Kingston Site. As time progresses, the radiation dose increases. The dose from radionuclides present in milk, drinking water, and from meat via water dependent pathways form the basis for the curve for K-40 shown previously in Fig.10. The dose received via water independent pathways (e.g., plant consumption and external dose) is primarily due to Ra-226 and is attributed to increased radionuclide availability for uptake in plant roots caused by the erosion of the clean topsoil. The decrease in dose (after approximately 150 years for water independent and 700 for water independent pathways) is attributed to a combination of leaching mobile radionuclides and erosion of the contaminated soil from the system.

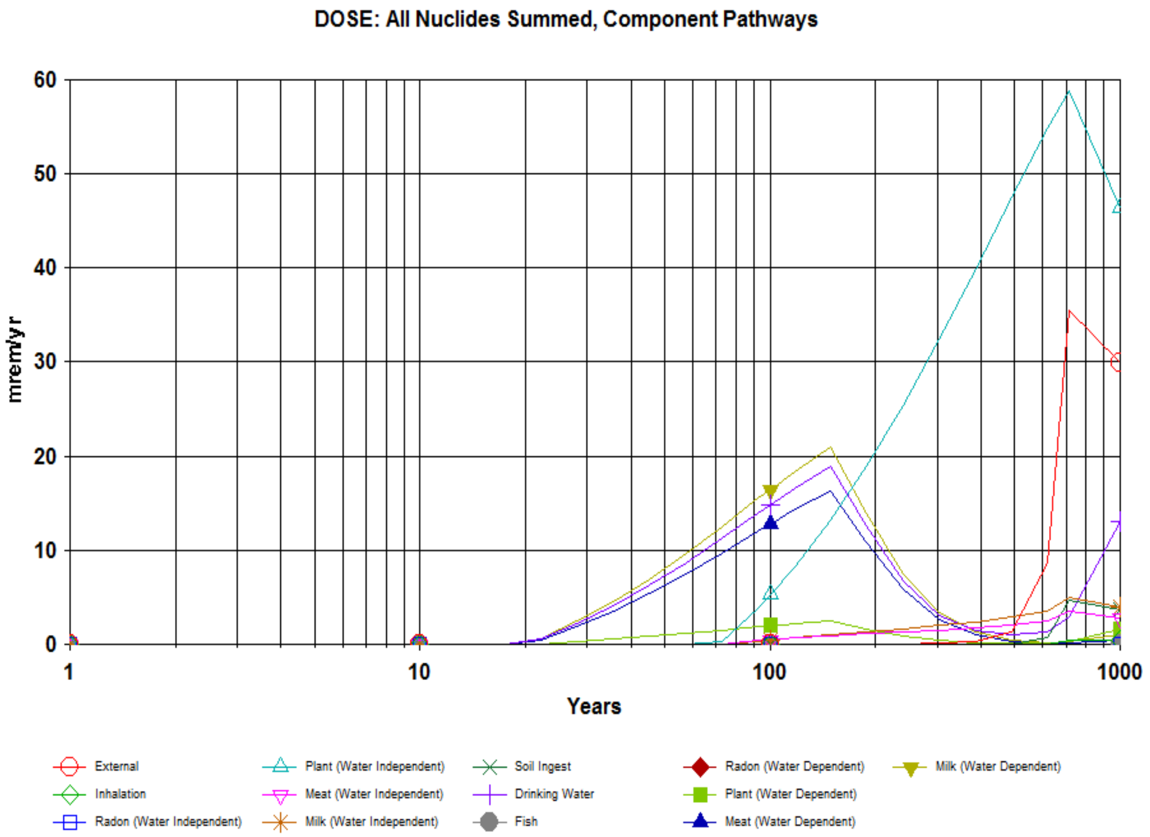


Figure 11: Results of the RESRAD data showing component pathways for all radionuclides at the TVA Kingston Site.

Figure 12 shows the component pathways for K-40 at the TVA Kingston Site. The data show that after 150 years there is a spike in K-40 intake. The main pathways for dose are milk, drinking water, and water dependent meat. The spike seems to indicate that K-40 has entered the water table, causing increased availability for uptake into plant roots and drinking water uptake and the decline would indicate the K-40 being flushed out of the system and removal due to erosion of top soil.

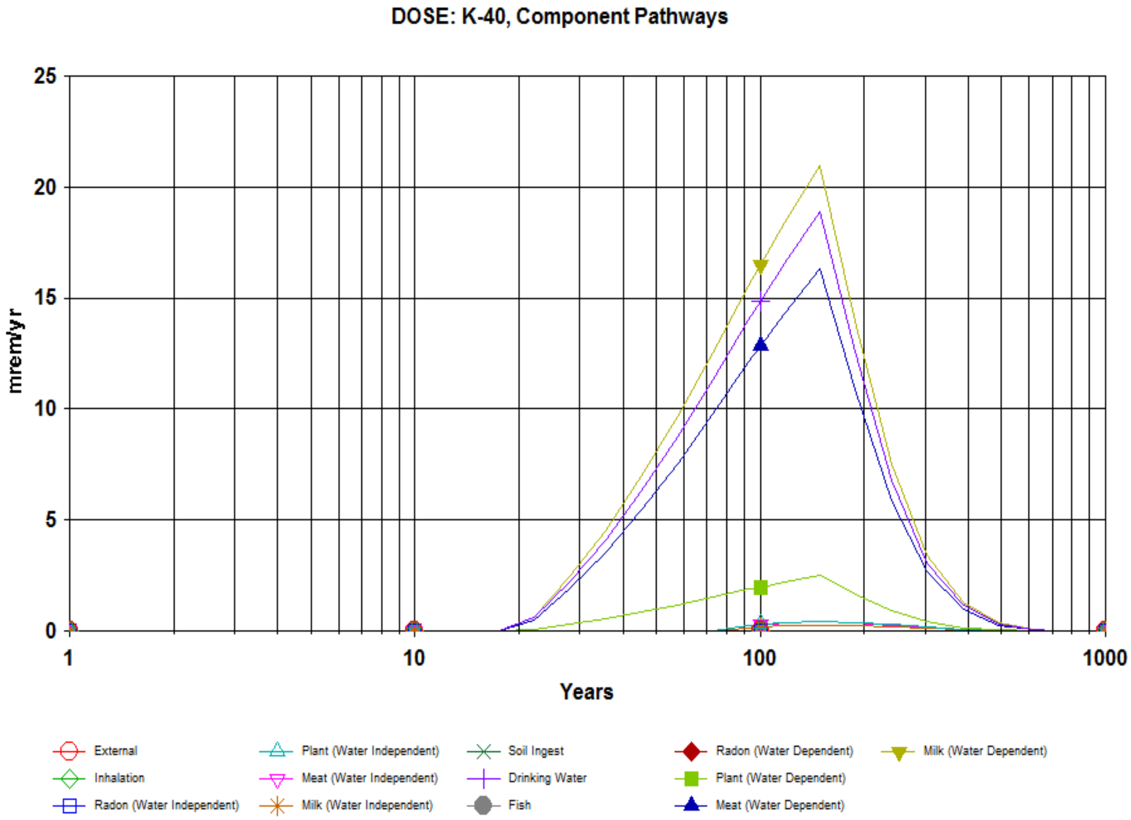


Figure 12: Results of the RESRAD data showing component pathways for K-40 at the TVA Kingston Site

Figure 13 shows the component pathways for Ra-226 at the TVA Kingston Site. The data shows that in the few years after year 100 until around year 700, there is a dramatic increase in Ra-226 dose. The spike in Ra-226 is two fold. The main dose is derived from water independent plants pathways. The spike in dose is the plants is caused by the topsoil eroding enough so that the plants roots have an increased uptake along with rainfall pushing the nuclides into the water table and that water subsequently being used to water the plants via surface irrigation. At the point of the beginning of the increase, the top soil is thin enough that the plants roots migrate to the contaminated soil. With the top soil eroded away, Ra-226 can also start causing an external dose, which is apparent on Figure 13.

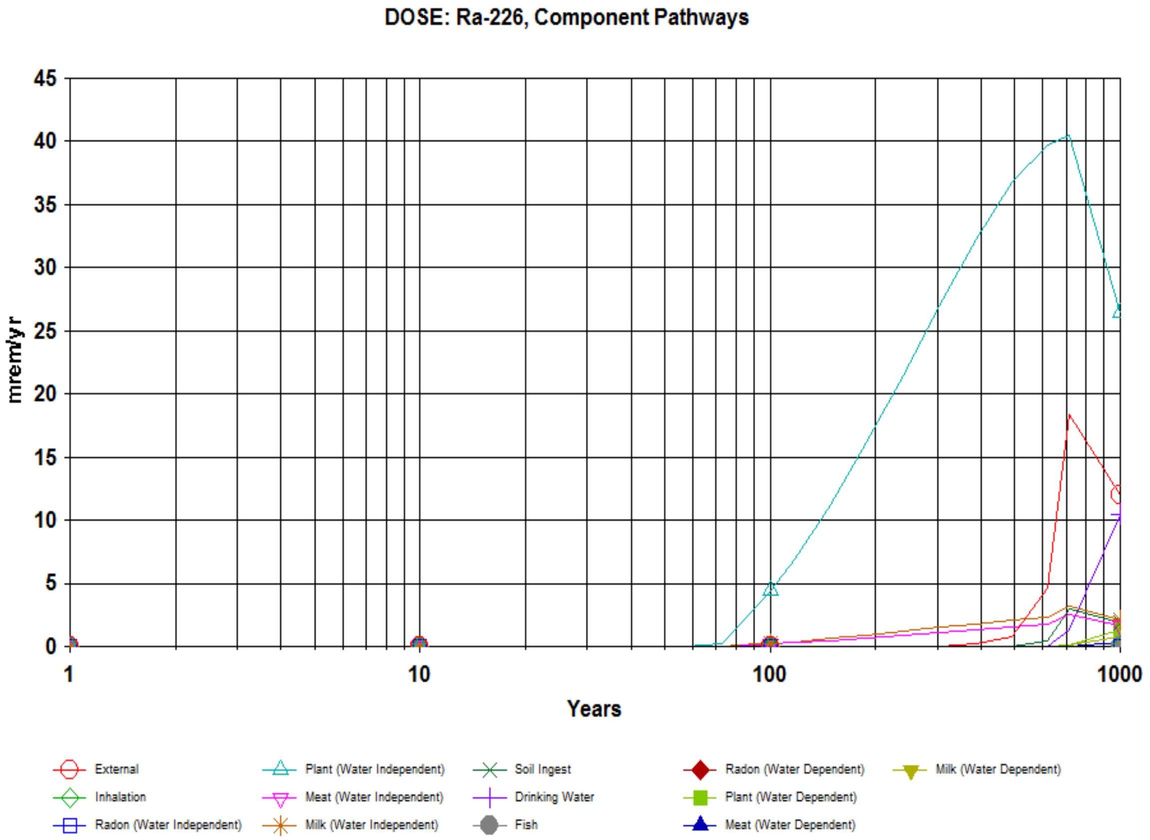


Figure 13: Results of the RESRAD data showing component pathways for Ra-226 at the TVA Kingston Site.

Figure 14 shows the water independent and dependent subtotals for all nuclides summed together. The water dependent totals spike around 50 mrem/y. The dose for the water independent pathways spikes at 105 mrem/y. The two different spikes are related to the two underlying radionuclides causing the main dose for this simulation. The water dependent dose is from K-40, while the water independent dose is primarily from Ra-226 and Th-232. The spike of water independent dose is primarily caused by the erosion of the topsoil, removing the top layer of clean soil, making available more contaminated soil available for plant root uptake and increase of external dose from the exposed source. The distribution coefficient of a radionuclide inversely identifies how a material will move with water. K-40 has a very low coefficient, 5.5 cm^3/g, which makes it soluble in water, while Ra-226, 70 cm^3/g, and Th-232, 60,000 cm^3/g are relatively less soluable.

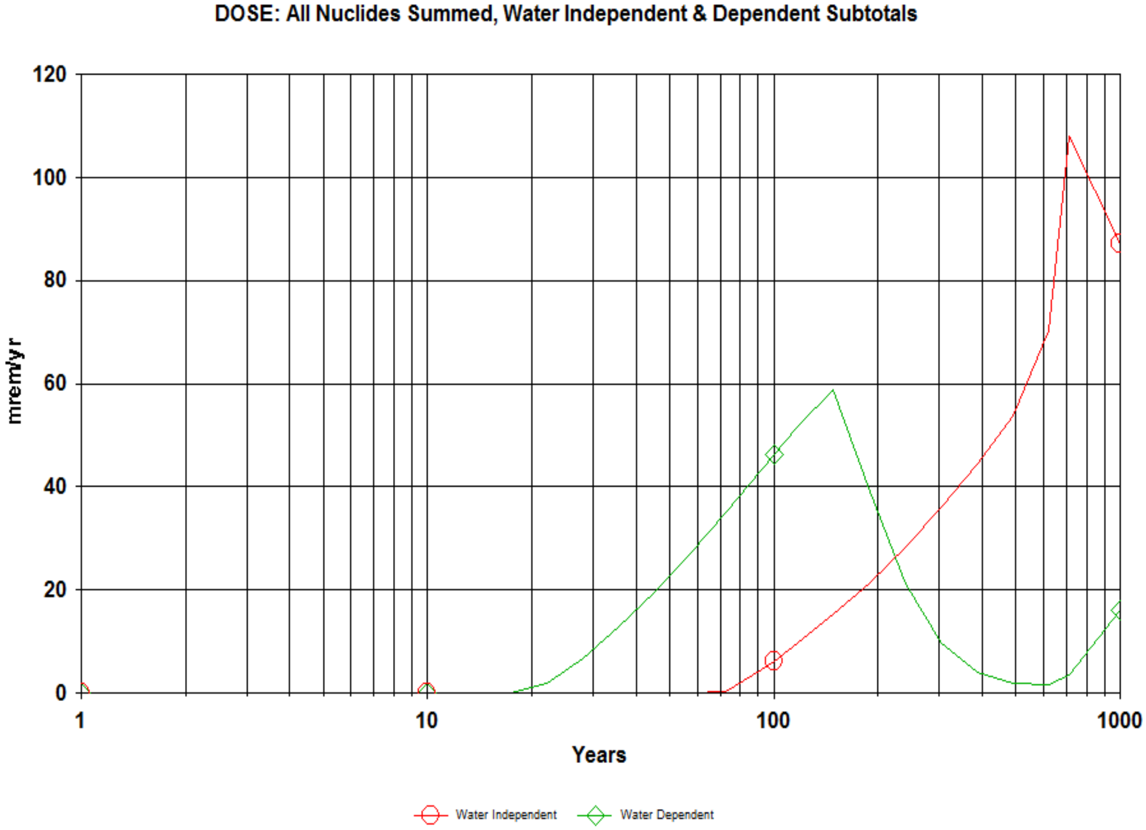


Figure 14: Results of RESRAD data showing water independent and dependent subtotals at the TVA Kingston Site.

Figure 15, shows that K-40 is primarily water dependent in this system. The reason that the K-40 is so prevalent in this system is due to the amount of rainfall in the reason. there is over 40” of rain in the TVA Kingston region yearly. This increased amount of rain paired with K-40 low distribution coefficient allowed for the nuclide to move through the system more readily. The sharp rise is due to the K-40 entering into the water supply, while the sharp decline is due to the K-40 being flushed out of the system and being removed from the source via erosion.

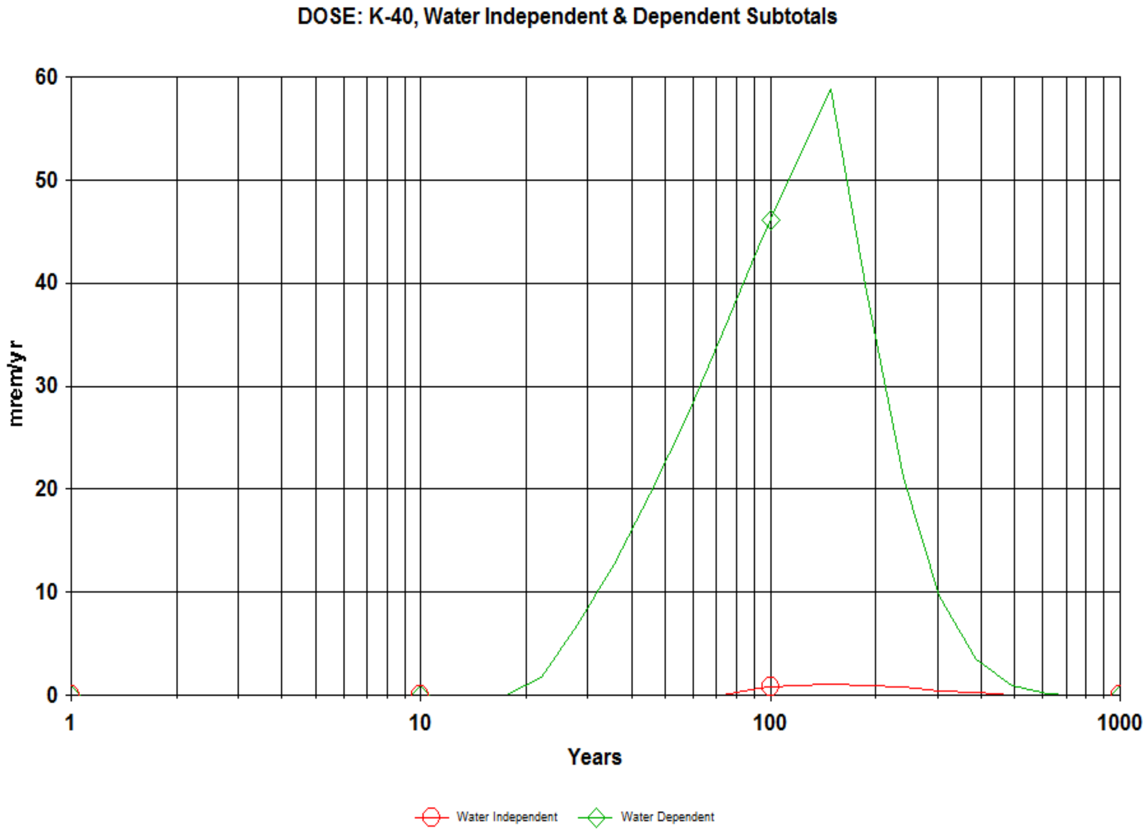


Figure 15: Results of RESRAD data showing water independent and dependent subtotals of K-40 at the TVA Kingston Site.

Figure 16, shows that Ra-226 is primarily water independent is this system. The sharp rise in Ra-226 is due to wind erosion removing the top layer of protective soil, while the sharp decline is due to the source material being blown out of the system via wind erosion and washed from the top layer of soil from rainfall and surface irrigation. Since Ra-226 is a heavier than air gas, once Ra-226 is airborne, the wind will move it from the area. The slight increase starting in year 700 notes that the Ra-226 has migrated into the water table.

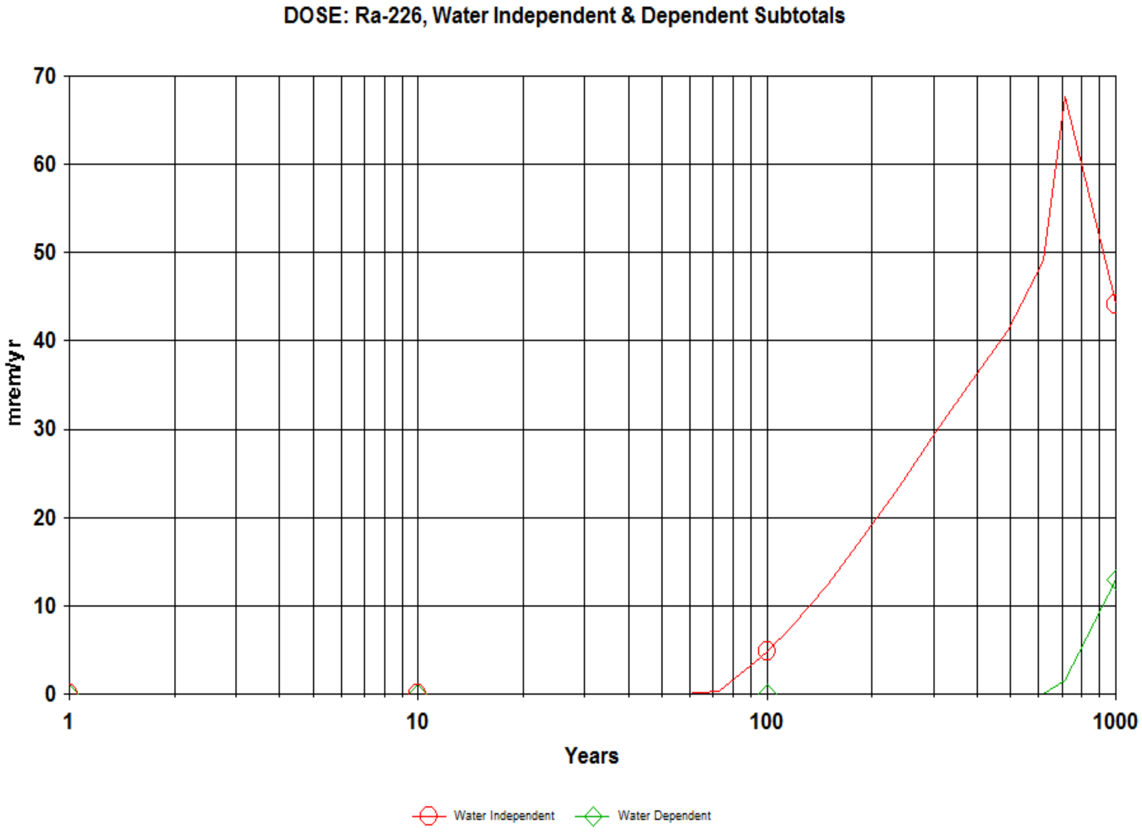


Figure 16: Results of RESRAD data showing water independent and dependent subtotals of Ra-226 at the TVA Kingston Site.

Figure 17, shows that Th-232 is primarily water independent is this system. The rise in Th-232 dose is attributed to the erosion, either wind or water erosion, of the top soil. The plateau is due to the Th-232 reaching its maximum dose rate.

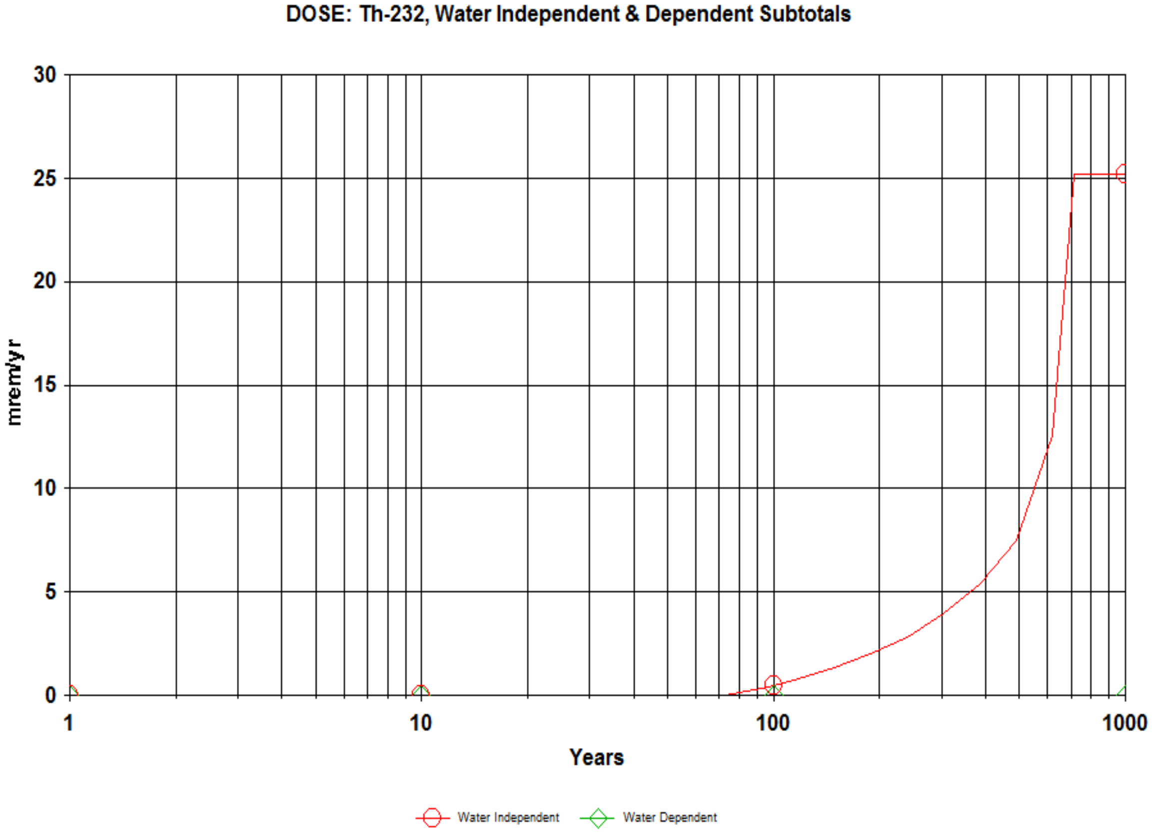


Figure 17: Results of RESRAD data showing water independent and dependent subtotals of Th-232 at the TVA Kingston Site.

PGE Boardman Site Results

The analysis for the PGE site is based on the radionuclide inventory provided for the coal ash after the TVA Kingston spill. The soil values used are from the area surrounding the PGE Boardman power plant.

Figure 18 shows the radiation dose an occupant would receive over background radiation levels for individual nuclides and a summed dose over a 1,000 year period at the PGE Boardman site. Unlike the TVA Kingston site, the dose curve is confined to only one spike and decline. The primary source of the dose originates from Ra-226. The spike is due to topsoil erosion of the soil cap, exposing the contaminated soil to the atmosphere. This erosion allows for increased Ra-226 exposure. The decrease of the Ra-226 exposure is due to the source being eroded away by the wind and removal by surface water removing source from the system.

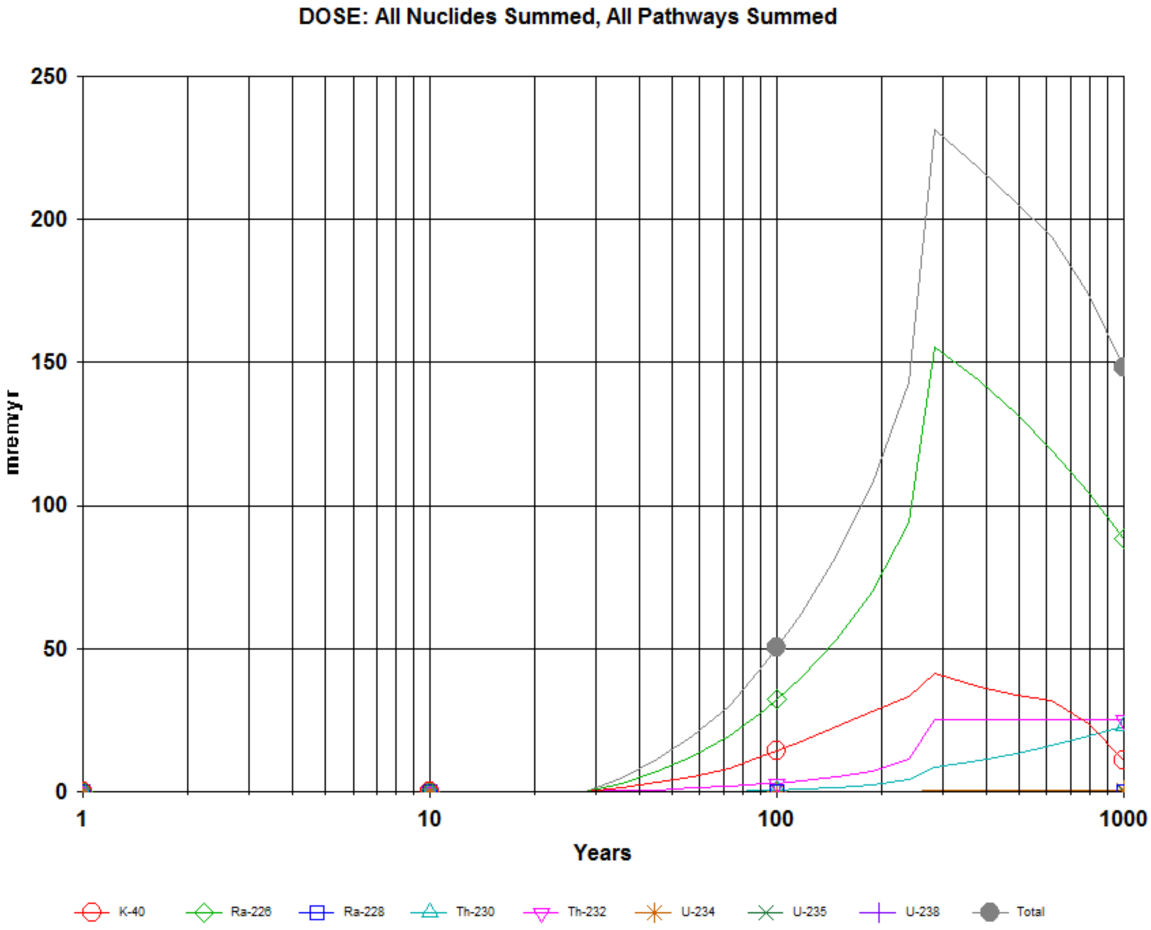


Figure 18: Results of the RESRAD data showing a resident's estimated dose at the PGE Boardman Site.

Figure 19 shows the radiation dose for each pathway for all radionuclides at the PGE Boardman site. As time progresses, the radiation dose increases. At the PGE site, the main dose is derived from the water independent plant and external pathways. These spikes are caused by the removal of the top soil via erosion. The spike in water independent plant and external dose is primarily due to Ra-becoming more available for uptake in plant roots caused by the erosion of the clean topsoil. The decrease in dose around year 300 from both of those pathways is also due to erosion of the contaminated soil from the system. The main difference is derived from the increased rate of erosion and lower yearly rainfall.

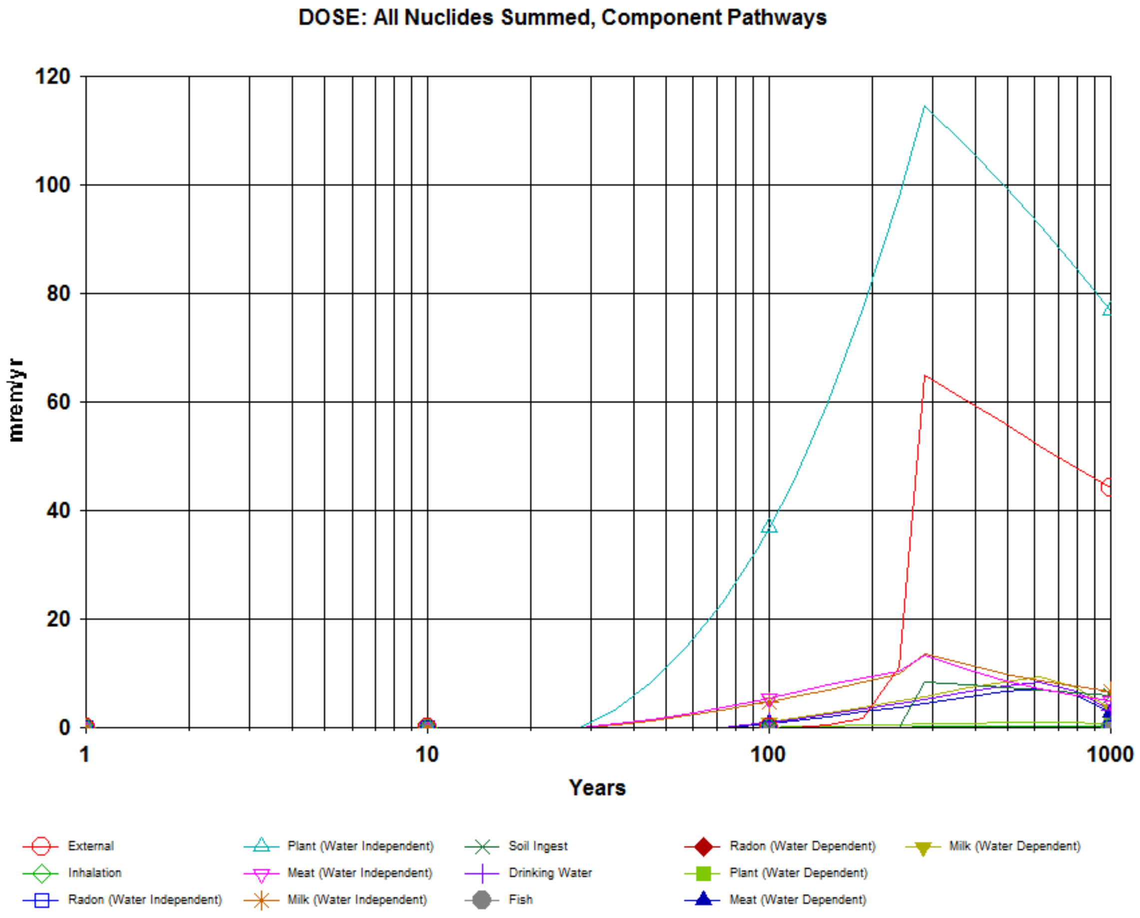


Figure 19: Results of the RESRAD data showing component pathways for all radionuclides at the PGE Boardman Site.

Figure 20 shows the component pathways for K-40 at the PGE Boardman site. The data show that overall in the few years after year 100 there is a spike in dose from K-40 intake. The K-40 dose has two distinct components that peak at years 300 and 600: the water independent, plant, milk, and meat pathways; and the water dependent, milk, meat, and drinking water pathways. The water independent dose is caused wind eroding the top soil, while the dependent pathways are signs that the K-40 has leached into the ground water and then into irrigation and drinking water.

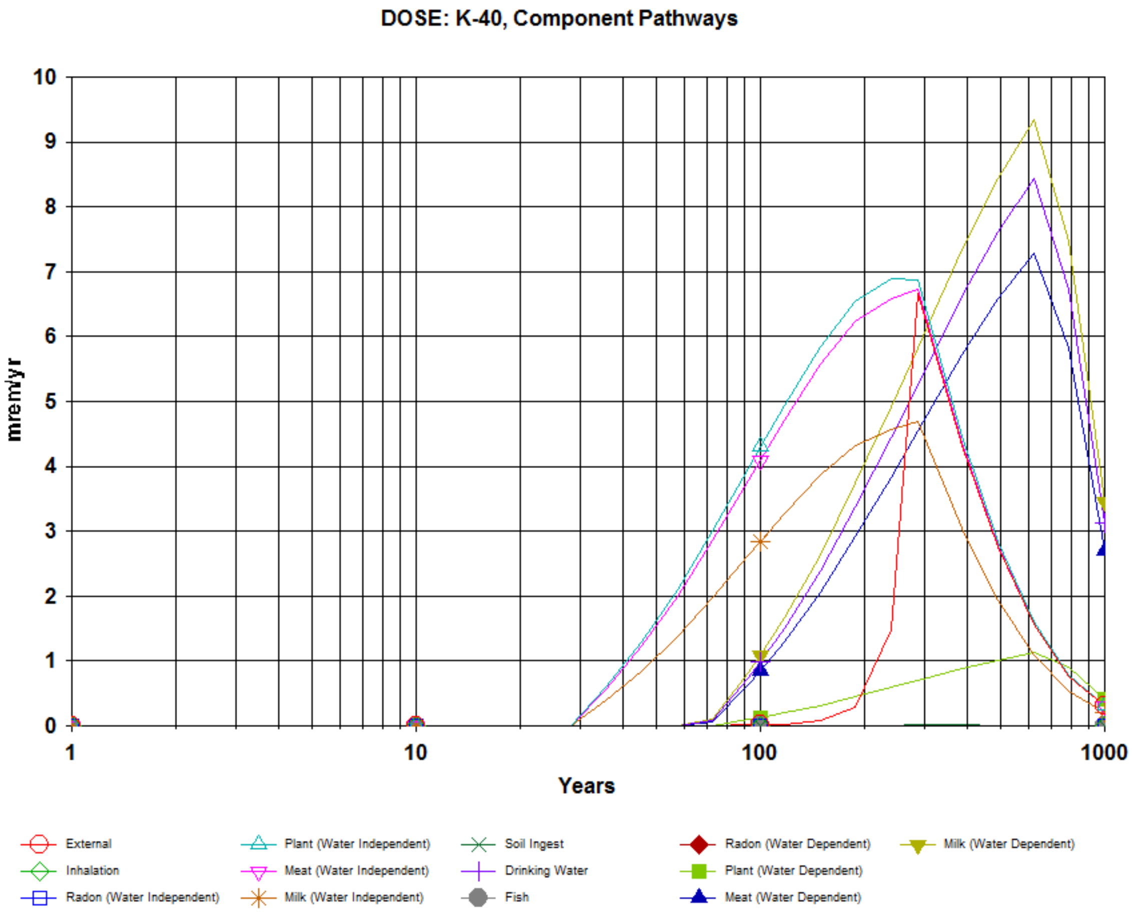


Figure 20: Results of the RESRAD data showing component pathways for K-40 at the PGE Boardman Site.

Figure 21 shows the component pathways for Ra-226 at the PGE Boardman site. The data show that in the few years after year 100 until around year 700, there is a dramatic increase in Ra-226 dose. The spike in Ra-226 is primarily from water independent plants and secondarily due to external exposure. The cause for the spike in water independent plant pathway is caused by the topsoil eroding enough so that the plants roots have an increased uptake along with rainfall pushing the nuclides into the water table and that water subsequently being used to water the plants via surface irrigation. The external exposure is the result of the erosion of the topsoil that covers the contaminated soil allowing for exposure.

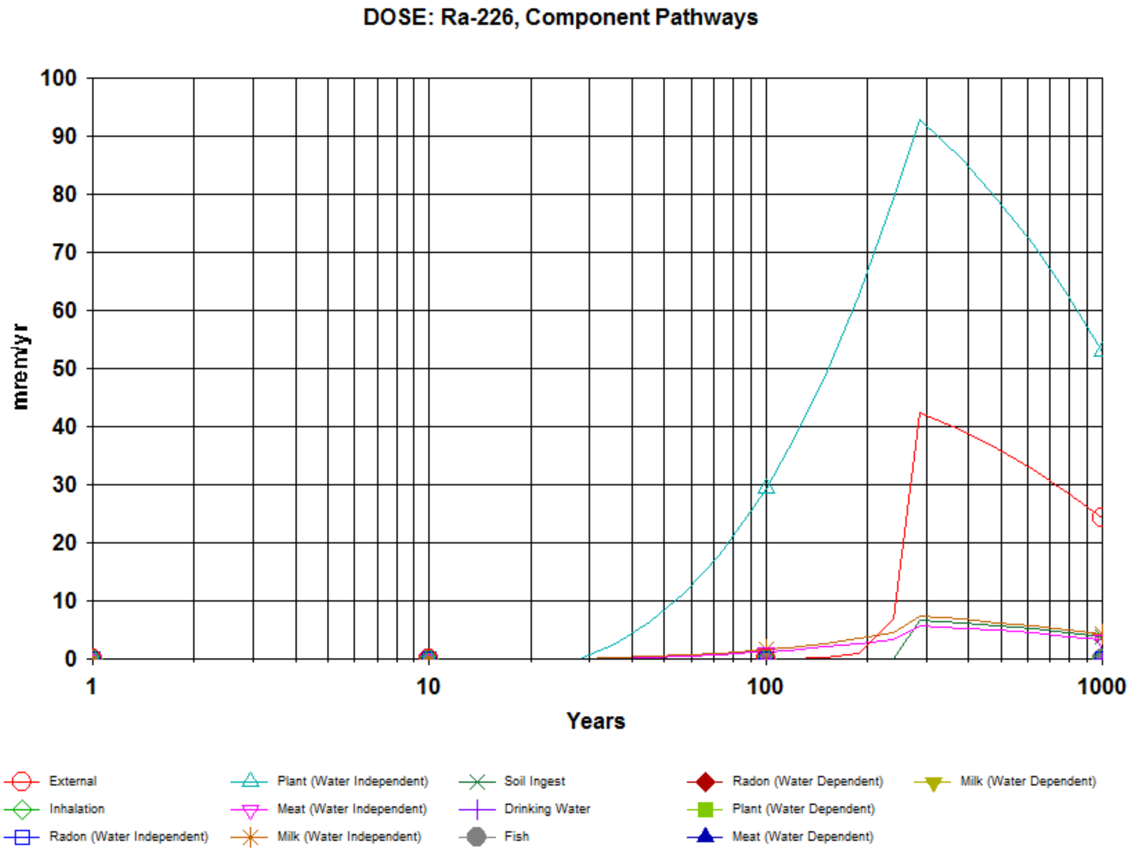


Figure 21: Results of the RESRAD data showing component pathways for Ra-226 at the PGE Boardman Site.

Figure 22 shows the water independent and dependent subtotals for all nuclides summed together. The water dependent totals spike around 25 mrem/y. The water independent spikes at around 215 mrem/y. The PGE Boardman site has less rainfall and higher wind erosion, which is evident in the graph. Since there is less rain, the overall water dependency is lower. The increased wind erosion increased the overall dose compared to TVA Kingston.

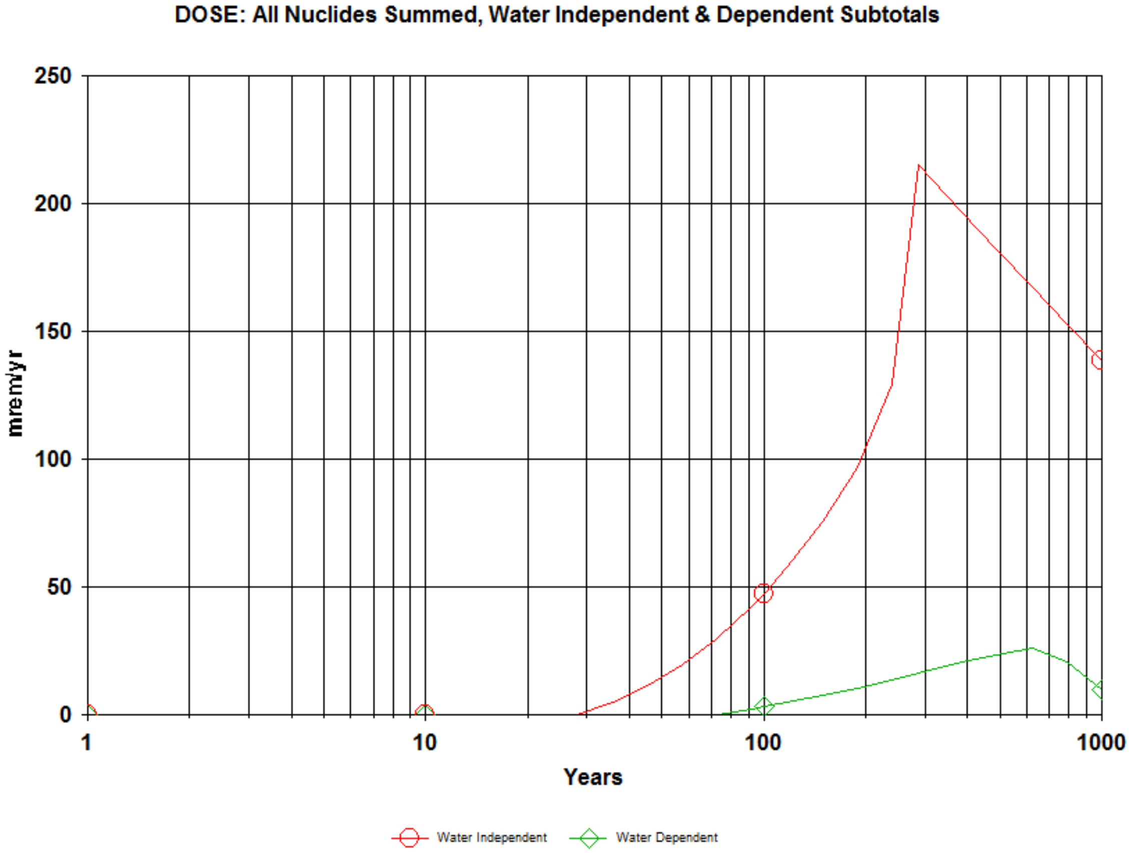


Figure 22: Results of RESRAD data showing water independent and dependent subtotals at the PGE Boardman Site

Figures 23 show the water independent and dependent values for K-40. The spike in dose is due to water independent pathways, primarily increasing due to wind erosion. The second spike is due to the K-40 migrating to the water table. This happened at a later time and at less of an intensity that at the TVA Kingston site due to the limited rain fall in the region.

Figure 23: Results of RESRAD data showing water independent and dependent subtotals of K-40 at the PGE Boardman Site.

Figure 24 shows the water independent of Ra-226. The spike's rise and fall are both attributed to the wind erosion in the region. This enhanced erosion rate increased the overall dose delivered by the Ra-226 at the PGE Boardman site compared to the TVA Kingston site. The enhanced wind erosion rate causes the source material to be more available for root uptake in plants and increase external dose to the reference man.

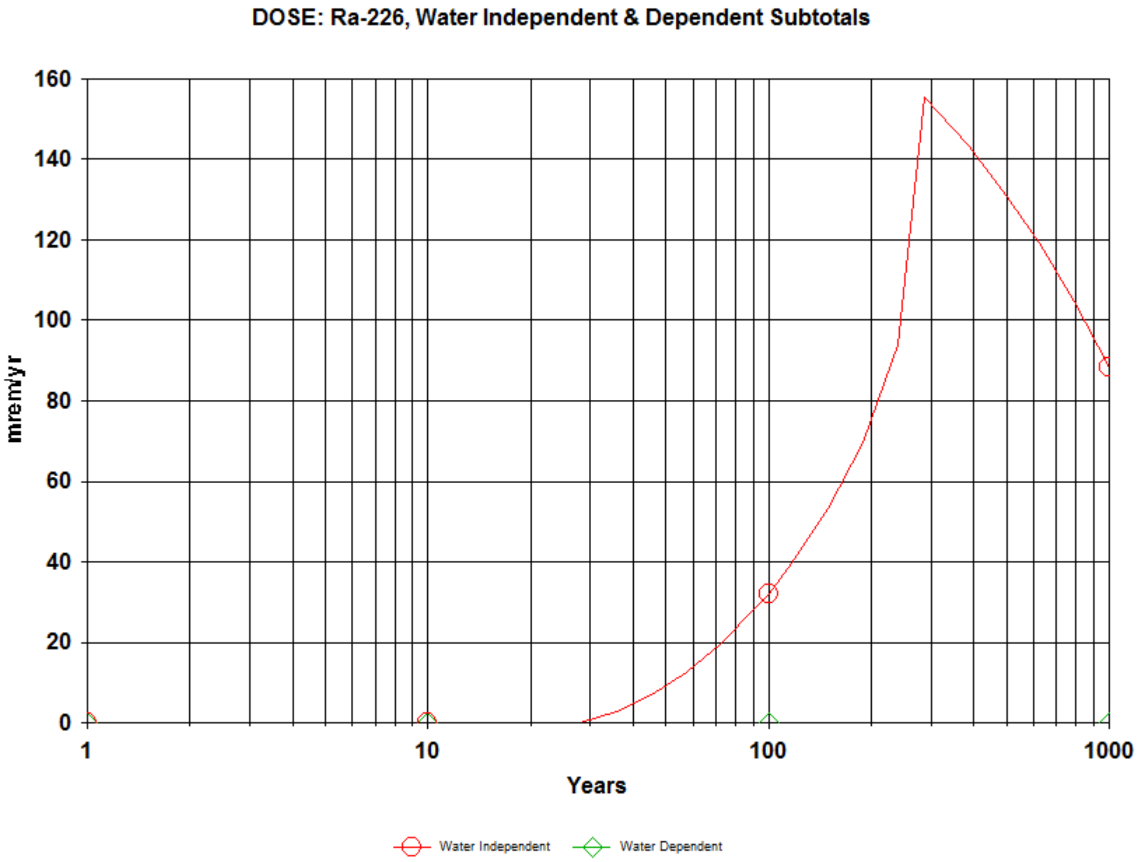


Figure 24: Results of RESRAD data showing water independent and dependent subtotals of Ra-226 at the PGE Boardman Site.

Figure 25 shows the water independent of Th-232. The spike's rise is attributed to the wind erosion in the region. The plateau is again attributed to Th-232 reaching its maximum dose rate. This enhanced erosion rate allowed Th-232 at the PGE site to reach equilibrium at a faster rate compared to the TVA site.

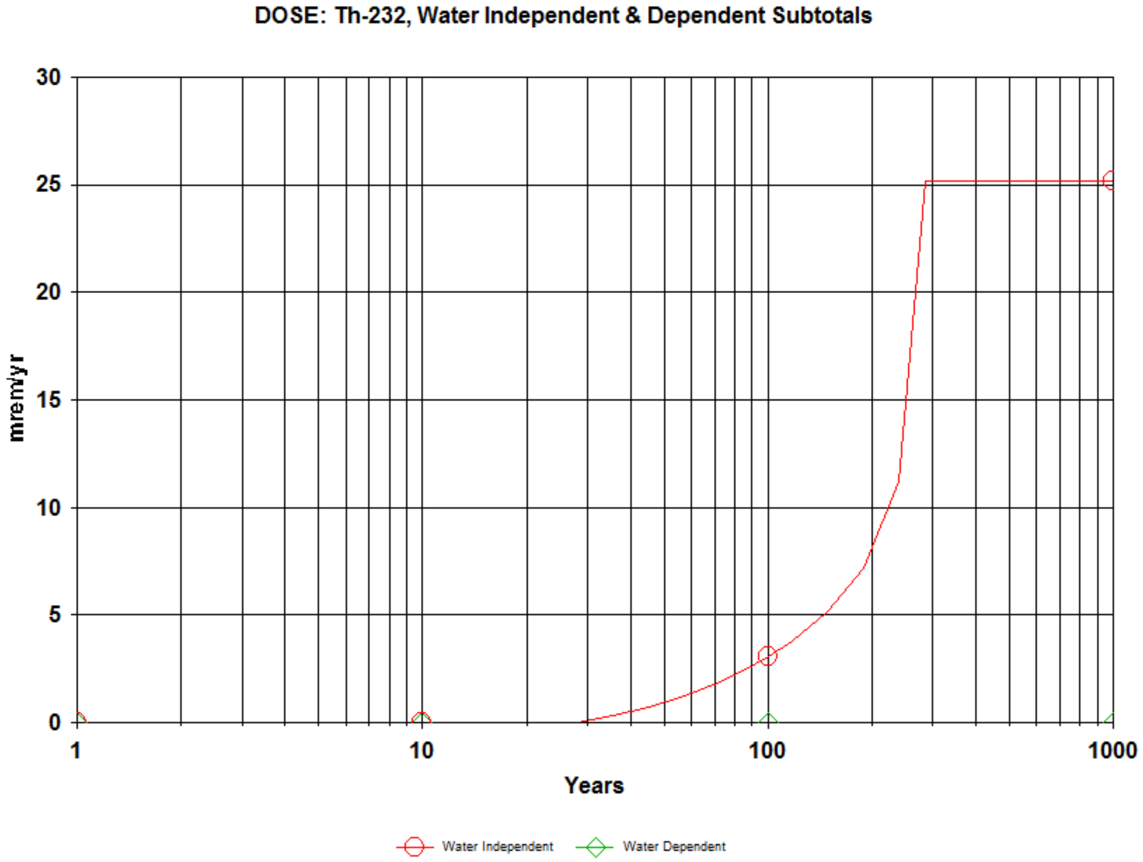


Figure 25: Results of RESRAD data showing water independent and dependent subtotals of Th-232 at the PGE Boardman Site.

Limitations of Analysis

Any dose calculations based on this set of data are purely suggestive and serve as an indicator of realistic environmental conditions. These estimates cannot be used to justify any actions outside of generating theoretical situations. There are many variables that need to be collected for an individual site to run accurate dose calculations. Meteorological, geographical, geological and political variables are keys to obtaining a proper dose calculation, and that data should be collected before applying this data to another location.

For the PGA Boardman site, the only variables used from the site were the soil information. The PGA site does not have the same quantity or burn the same type of coal as the Kingston site and is purely used to compare soil samples.

Discussion

The data analysis here indicates that the 25-mrem/y dose for the first 1000 years is greatly exceeded. The 100 mrem/y limit on radiation exposure to the general public is also exceeded. The 5000 mrem/y limit on radiation for a U.S. radiation worker is not exceeded.

TVA Kingston Site Analysis

The maximum received dose for the TVA Kingston site is 111.6 mrem/y occurring at year 714. The majority of the dose occurs from water independent plants (68 mrem/y), external dose (35 mrem/y), and milk (21 mrem/y). Of the dose received from K-40 a maximum of 22 mrem/y was from milk, 18 mrem/y from drinking water and 16 mrem/y from meat. Of the dose received from Ra-226, most was via water independent plants (40 mrem/y). The doses received from water dependent pathways have a maximum value of 58 mrem/y, while water independent pathways have a maximum of 107 mrem/y. The pathway for K-40 was primarily water dependent while Ra-226 and Th-232 were primarily water independent. Overtime, the rainfall in the region moved the K-40 from the contaminated soil into the water table, causing the vast majority of the water dependent dose. Once the water from the water table was used for irrigation, the plant root uptake of K-40 increased. The wind erosion removes the topsoil cap after a period of time, evident by the increased external dose from Ra-226. Once the topsoil cap has been compromised, the rainfall and irrigation water flushes the K-40 down into the water table, while removing some of the surface contaminants containing Ra-226 out of the system.

PGE Boardman Site Analysis

The data trends for the PGE Boardman site were similar to those at TVA Kingston. The maximum dose was 231.3 mrem/y at year 285. The greatest difference was the smaller K-40 peak and larger Ra-226 peak, which affected the water independent and dependent values. The initial spike from K-40 exposure seen in the TVA Kingston data was absent from the PGE Boardman data. This decrease in K-40 is primarily due to the minimized rainfall rate at PGE Boardman site. The increase in the Ra-226 exposure is caused by the enhanced erosion rate at the PGE Boardman site. The combination of less rainfall and increased erosion rates of the topsoil increased the water independent dose while lowering the water dependent dose. This difference is caused by the rainfall amount, erosion coefficient and hydraulic conductivity of the soil at PGE Boardman. Overall the dose at the PGE Boardman site is significantly higher due to these changes in environment.

Conclusion and Recommendations

According to these results, coal ash ponds can be a significant source of radiological exposure. Of the two sites, the PGE Boardman site would result in the greatest mrem/y. This is due to the soil type and meteorological impact on the area. Both sites were well above the 25 mrem/y limit for a decommissioned nuclear site. The primary radionuclides responsible for the dose are K-40 and Ra-226.

Because of the sheer number of coal power plants located in the U.S. and around the world, there is a large amount of coal ash generated every year. TVA states that the coal ash that was spilt had a relative activity less than low sodium salt. That is fine until a farm and a house are built over a couple million tons of radioactive material. The coal ash radionuclides are different and move through different pathways.

In order to begin meeting any sort of radiological regulations, the coal plant will need to retrofit their existing coal ash ponds. Utilizing materials that have a very low hydraulic coefficient will minimize the amount of material that seeps out of the bottom of the pile and into the local water system. Currently coal plants place about three feet of topsoil to minimize environmental erosion moving the coal ash into the environment. These modifications will also minimize the non-radiological material from entering the environment. The use of a well onsite would also need to have special guidelines to minimize the possible effects of drilling through the protective sub-layers stopping the coal ash components from leaching into the water supply.

Potential Problems

If the coal power industry has to retrofit their coal ash ponds, the cost of those modifications will be passed on to the consumer. These modifications could have a significant impact on the local economies in areas that rely heavily on coal power production.

This increase in cost of operation for coal power plants would increase the cost per kilowatt increases for coal power; the cost for nuclear energy is relatively static, making the cost for nuclear energy more cost competitive.

Future work

The data used for this project were obtained from the evaluation of one site. Each coal power plant's data will differ based on meteorological, geographical, geological, political, and quality of fuel being burned.

1. Site Specific Data

In order obtain accurate site specific doses, more data will need to be collected from that site. Soil, coal, and coal ash compositions, meteorological, structural design, and coal ash storage procedures are different for all plants and need to be taken into consideration when calculating radiological doses.

2. Conduct a thorough investigation of site specific construction

There needs to be an investigation into how the coal plants are moving the coal ash, how the coal ash is stored, and the import and export of coal ash from the site. These variables can affect how the coal ash enters into the local environment.

3. Conduct an economical assessment for retrofitting existing ponds

In order to be competitive to decommissioning standard for nuclear facilities, there will need to be extensive retrofitting completed at most coal power plants. An economical cost analysis of how the retrofitting requirements will affect the overall cost of energy would need to be conducted to identify any detrimental costs. It would need to be determined if it would be cost effective to invest in nuclear power and develop methods to create nuclear power fuel from the coal ash.

The assessment would also look into alternative uses for the coal ash and ways to keep the coal ash pond quantities at a minimum level, so that if a spill occurs, it will have minimal impact.

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