RADIONUCLIDE DISCHARGES TO ONSITE EVAPORATION PONDS
AND CONSEQUENT DOSES

Prepared for ANPP
by
Environmental Services Division
NUS Corporation

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I. INTRODUCTION

This report presents information on the effects of continuing discharges of radionuclides to the onsite evaporation ponds from three units of the Palo Verde Nuclear Generating Station (PVNGS) over its operating lifetime. The evaluation assumed continuous discharges from the secondary systems over a forty-year plant operating lifetime, followed by a drying-out of the ponds after plant shutdown. Two source terms were considered: the first consisted of discharges at concentrations expected to exist in the secondary system condensate, and the second assumed discharges at minimum detectable concentrations.

For each source term and consequent radionuclide inventory in the pond, doses were evaluated with and without an assumed remedial action being implemented after the plant was decommissioned. The remedial action was assumed to be the covering of the dried pond sediments with two feet of earth. Since the radionuclides would be added to the pond together with water containing (nominally) 12,000 mg/liter, the nuclides were assumed to be uniformly distributed in the pond sediments at the end of plant life.

The doses considered were the direct gamma dose to an individual continuously exposed at the center of the pond area, and the dose from inhalation of resuspended sediments to an individual at the edge of the pond area. Ingestion doses were not considered credible due to the chemical constituents of the pond sediments from cooling tower blowdown. The calculated doses are compared with dose limitations in present and proposed versions of 10CFR20 and with the EPA 40CFR190 dose guidance.

II. SOURCE TERMS AND POND INVENTORIES

Liquid discharges to the evaporation pond were assumed to continue over a forty-year operating lifetime for PVNGS. Two radionuclide discharge rates were assumed in order to provide corresponding pond inventories: the first assumed radionuclide releases at expected secondary system condensate concentrations (FSAR, Table 11.1-7); the second assumed releases at concentrations corresponding to the lower limit of detectability (LLD), as defined in Technical Specification 3.11.1.1. In both cases, a blowdown rate to the ponds of 25,000 gallons per unit per day was assumed as the regenerant volume (1), as well as a discharge of Antimony-124 at a concentration of 2.0E-05 µCi/ml (10CFR20, Appendix B, Table II, Column 2). For the second case, the LLD for all gamma-emitting radionuclides was taken as 5.0E-07 µCi/ml, except for Ce-144 (5.0E-06 µCi/ml) and I-131 (1.0E-06 µCi/ml).

Radionuclide inventories resulting from these two discharge rates were calculated for an operating lifetime of 40 years, followed by a decay period corresponding to the time required for the pond water to evaporate following plant shutdown. Based on a mean pond depth of 23.8 feet (2) and a net lake evaporation rate of 7.21 feet per year (3), a period of 3.3 years can be calculated as required for the ponds to dry out. Seepage and runon were assumed to be negligible due to the essentially impermeable pond liner and the berm surrounding the ponds, respectively.

To determine concentrations of the accumulated radionuclides, the cumulated quantity of solids discharged to the pond in cooling tower blowdown over the operating period were also calculated. Based on the nominal blowdown concentration of 12,000 mg/l (ER-OL, Table 3.6-1) and the average plant waste flow to the evaporation pond of 2800 gpm (ER-OL, Figure 3.3-1), the accumulated solids over the forty-year period are calculated to total 2.69E09 kg. The pond surface area was assumed to be 475 acres, the sum of the areas of the existing pond and the 225 acre pond currently under construction; the expected maximum pond area of 670 acres (ER-OL, 3.6.3.1) would result in lower concentrations and doses.

The calculated inventories of nuclides present in significant quantities (greater than 1 microcurie) at the end of the 43.3 year operating-plus-drying-out period are listed in Tables II.1 and II.2 for the expected and the LLD cases, respectively. The tables include quantities of each radionuclide in curies; concentrations in picocuries per gram of solids; and (hypothetical) surface densities in picocuries per square meter of pond area (i.e., neglecting the inert solids present and assuming radionuclides are present in a thin film).

Table II.1 Radionuclide Inventories, Concentrations and Surface Densities in the PVNGS Evaporation Ponds at 43.3 Years for Expected Releases.*

Nuclide	Dry Pond Inventory (Ci)	Nuclide Concentration (pCi/g)	Surface Density (pCi/sq m)
Fe-55	3.06E-05	1.14E-05	1.59E+01
Co-60	1.22E-04	4.56E-05	6.39E+01
Sr-90	2.88E-06	1.07E-06	1.50E+00
Cs-134	3.11E-04	1.15E-04	1.62E+02
Cs-137	5.51E-03	2.05E-03	2.87E+03
Sb-124	4.45E-07	1.65E-07	2.32E-01

* inventories › 1 µCi (except Sb-124)

Table II.2 Radionuclide Inventories, Concentrations and Surface Densities in the PVNGS Evaporation Ponds at 43.3 Years for Releases at LLD *

Nuclide	Dry Pond Inventory (Ci)	Nuclide Concentration (pCi/g)	Surface Density (pCi/sq m)
Mn-54	3.95E-03	1.47E-03	2.06E+03
Fe-55	8.04E-02	2.99E-02	4.19E+04
Co-60	2.56E-01	9.53E-02	1.33E+05
Sr-90	1.21E+00	4.48E-01	6.27E+05
Ru-106	7.82E-03	2.90E-03	4.05E+03
Te-127m	1.05E-05	3.91E-06	5.47E+00
Cs-134	5.02E-02	1.86E-02	2.61E+04
Cs-137	1.25E+00	4.65E-01	6.52E+05
Ce-144	3.08E-02	1.14E-02	1.60E+04
Sb-124	4.45E-07	1.65E-07	2.32E-01

* inventories › 1 µCi (except Sb-124)

With radionuclide inventory and concentration values, doses from direct external exposure can be calculated. However, estimates of particulate concentrations resulting from resuspension of pond sediments, are also required to permit determination of inhalation doses.

For exposure of an individual from inhalation of resuspended radionuclides due to wind erosion, an emission factor formula for "wind erosion from exposed areas" (4) was used to calculate an emission rate for the dry PVNGS evaporation pond sediment beds. The factors involved in the formula include soil erodability, frequency of wind speeds above a threshold (12 mph), silt content, and the Thornthwaite Precipitation-Evaporation Index.

The erodability factor is a function of the predominant soil textural class of the material subject to wind erosion. The material in pond sediments is not soil, of course, but rather the concentrated inorganic salts in the blowdown of the cooling towers which would be expected to crystallize and form a surface crust during the drying-out process. During the course of the forty years of plant operation, fugitive emissions of surface soils and dusts from the surrounding environs will likely be transported and deposited by winds into the PVNGS evaporation ponds. For the purposes of this analysis. these soils are conservatively assumed to establish the required re-entrainment parameters.

On the basis of a soil study conducted as part of the ongoing PVNGS salt deposition and impact monitoring program (5), the predominant soil texture class surrounding the PVNGS is sandy loam. Sandy loam soil has an associated erodability factor of 86 (Table A-1 of Reference 4). In the absence of textural characteristics of the evaporation pond sediments, this value was chosen to conservatively represent the erodability factor for the dry evaporation pond sediment beds. Following the same reasoning, the silt content of sandy loam soil may range up to 50 percent (6), and a conservative value of 50 percent was used in the emission factor formula.

Meteorological data for 1986, the most recent complete calendar year, has been demonstrated to be representative of the longer-term PVNGS meteorological data averages (7,8), and was chosen for the air quality dispersion modeling analysis discussed in section III. The frequency of wind speed exceeding 12 mph in 1986 at the 35-foot level of the PVNGS meteorological tower was about 9 percent.

Finally, a P-E index value of 18 was selected for Thornthwaite's Precipitation-Evaporation Index for the PVNGS state climatic division (Figure 11.2.2, Reference 4).

These parameters yield an estimated particulate resuspension

source term of about 54,000 lbs/acre per year, or 1.9E-04 grams/sec-sq m.

III. DOSE PATHWAYS AND ESTIMATES

Direct Exposure Analysis

For the direct exposure, unremediated case calculations, an individual was assumed to stand in the center of the dry pond area on the surface of a sediment layer in which the inventory of radionuclides is uniformly mixed. An additional external dose calculation was performed assuming remedial actions after plant shutdown placed a two foot soil cover over this sediment layer.

Five radionuclides impart essentially 100 percent of the external doses at 43.3 years, for both the LLD and expected cases. These are Cesium-134, Cesium-137, Ruthenium/Rhodium-106, Manganese-54 and Cobalt-60. Antimony-124 decays to insignificant levels for both cases 3.3 years after discharges to the pond have ceased, because of its relatively short half life of 60 days.

The dose contributed by each of these radionuclides was calculated (9) for each source term both with and without the two foot earth cover. The density of the sediment was assumed to be 125 lbs/cubic foot (s.g. = 2.0) and 100 lbs/cubic foot (s.g. = 1.6) for the earth cover. The exposed and shielded external ground exposure doses for the expected and LLD source terms are presented in Table III.1 by nuclide, and indicate that, even with LLD releases for forty years, continuous exposure to unshielded sediments would produce a total dose of about 2.2 mrem/year.

Table III.1 Annual External Gamma Doses From Direct Ground Plane Exposure to Dried Sediments at the Center of the Evaporation Pond Area at 43.3 years (millirem per year)

	LLD Releases		Expected Releases	
Nuclide	Exposed	Shielded	Exposed	Shielded
Mn-54	8.09E-03	7.33E-06	3.76E-07	3.42E-10
Co-60	1.12E+00	3.16E-03	5.39E-04	1.51E-06
Ru/Rh-106	2.15E-03	2.02E-06	5.12E-09	4.83E-12
Sb-124	1.31E-06	6.34E-10	1.31E-06	6.34E-10
Cs-134	1.13E-01	1.39E-04	7.02E-04	8.56E-07
Cs-137	9.98E-01	1.08E-03	4.39E-03	4.76E-06
Total	2.24E+00	4.39E-03	5.64E-03	7.13E-06

Resuspension Analysis

The United States Environmental Protection Agency (USEPA) Industrial Source Complex Long-Term (ISCLT) dispersion model (10) was used to model the expected air quality impacts of suspended particulates from wind erosion of the PVNGS dry evaporation pond sediment beds. Two square area sources were used to represent the configuration of the two evaporation ponds due to model constraints. . Consequently, each area source was modeled with an equal side length of 980 meters to approximate the total 475 acre area of the two ponds.

Discrete receptor points were defined at 100 meter intervals around the perimeter at a distance of 101 meters from the edge of the ponds. The onsite PVNGS meteorological data for 1986 was processed and additional parameters required by the model were entered, including average mixing heights, average temperatures, wind speed profile exponents, and vertical potential temperature gradient.

The model assumed simple, flat terrain, using a code option which models only erosion cases, i.e., wind speeds of 12 mph or greater. The maximum annual average airborne concentration was calculated to be 2.34E+02 micrograms per cubic meter and to occur northeast of the evaporation ponds. Using this mass concentration and the radionuclide concentrations presented in Tables II.1 and II.2, inhalation doses were calculated for the bare pond sediment case only and are presented in Tables III.2 and III.3 for the expected and LLD sources, respectively. An average inhalation rate of 8000 cubic meters per year was used and inhalation dose conversion factors from Reference 11 were assumed. As noted in these Tables, the maximum inhalation dose to the critical organ, produced by Sr-90 in the LLD case, is about 0.011 mrem/year.

Table III.2 Annual Inhalation Dose to Maximally Exposed Individual (Teenager) From Resuspended Evaporation Pond Sediments After 43.3 Years, Expected Inventory *

Nuclide	Air Concentration (pCi/cu m)	Organ Dose (mrem/yr)	Total Body Dose (mrem/yr)
Fe-55	2.66E-09	3.30E-10	1.47E-11
Co-60	1.07E-08	9.31E-08	2.12E-10
Sr-90	2.51E-10	2.71E-08	1.68E-09
Sb-124	3.87E-11	1.49E-10	6.50E-13
Cs-134	2.70E-08	3.05E-08	1.48E-08
Cs-137	4.79E-07	4.06E-07	1.49E-07
		Total	1.66E-07

* inventories › 1 µCi (except Sb-124)

Table III.3 Annual Inhalation Dose to Maximally Exposed Individual (Teenager) From Resuspended Evaporation Pond Sediments After 43.3 Years, LLD Inventory *

Nuclide	Air Concentration (pCi/cu m)	Organ Dose (mrem/yr)	Total Body Dose (mrem/yr)
Mn-54	3.43E-07	6.81E-07	2.88E-09
Fe-55	6.99E-06	8.64E-07	3.87E-08
Co-60	2.23E-05	1.94E-04	4.42E-07
Sr-90	1.05E-04	1.13E-02	7.01E-04
Ru-106	6.80E-07	1.10E-05	8.41E-09
Sb-124	3.87E-11	1.49E-10	6.50E-13
Te-127m	9.16E-10	1.51E-09	2.00E-12
Cs-134	4.36E-06	4.92E-06	2.39E-06
Cs-137	1.09E-04	9.23E-05	3.38E-05
Ce-144	2.67E-06	3.57E-05	7.02E-07
		Total	7.38E-04

* inventories › 1 µCi (except Sb-124)

IV. CONCLUSIONS

An examination was made of credible pathways for exposure to pond sediments assuming their continuing contamination by discharges at expected concentrations and at Technical Specification limits for a forty year plant operating lifetime, followed by a period of 3.3 years during which the pond water evaporated. These pathways were direct exposure and inhalation of resuspended sediments. Consequences of a remedial action, covering the sediments with a two-foot earth cover, was also examined.

The results of continuous discharges for forty years at concentrations representing the lower limit of detectability would result (after the 3.3 year drying period) in a direct dose of 2.2 mrem/year from continuous exposure to the bare sediments and a maximum inhalation (organ) dose of about 0.01 mrem/year. These doses are significantly less than the standards in the current (500 mrem/year) or proposed (100 mrem/year) versions of 10CFR20, or in the EPA Environmental Standards for the Uranium Fuel Cycle (40CFR190.10) of 25 mrem/year. The covering of the sediments with two feet of earth at the end of the plant life would essentially eliminate inhalation doses, and reduce the direct gamma dose to trivial values (less than .01 mrem/year).

It is concluded that discharges could substantially exceed the limits currently defined in Technical Specification 3.11.1.1 without exceeding the EPA fuel cycle dose limits.

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