energy harbor

Energy Harbor Nuclear Corp
Perry Nuclear Power Plant
10 Center Road
Perry, Ohio 44081

Rod L. Penfield
Site Vice President, Perry Nuclear

440-280-5382
724-462-0816 (cell)

April 27, 2022
L-22-105

10CFR50.36(a)

ATTN: Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT:
Perry Nuclear Power Plant
Docket No. 50-440
Annual Radiological Effluent Release Report

Enclosed is the Annual Radiological Effluent Release Report for the Perry Nuclear Power Plant (PNPP) for the period of January 1, 2021 through December 31, 2021. This document partially satisfies the requirements of the PNPP Technical Specifications (TS), the PNPP Offsite Dose Calculation Manual (ODCM), and the Environmental Protection Plan contained in Appendix B of the PNPP Operating License.

There are no regulatory commitments contained in this letter. If there are any questions or if additional information is required, please contact Mr. Eli Crosby, Chemistry Manager at (440) 280-5032.

Sincerely,

Rod Penfield

Enclosures:
A PNPP 2021 Annual Radiological Effluent Release Report

cc: NRC Project Manager
NRC Resident Inspector
NRC Region III

Enclosure A

L-22-105

PNPP 2021 Annual Radiological Effluent Release Report

2021 Annual Radioactive Effluent Release Report

Document Number: L-22-105

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TABLES

FIGURES

LIST OF ACRONYMS AND DEFINITIONS

1. ARERR: Annual Radioactive Effluent Release Report
2. AREOR: Annual Radiological Environmental Release Report
3. Alpha Particle (α): A charged particle emitted from the nucleus of an atom having a mass and charge equal in magnitude of a helium nucleus.
4. BWR: Boiling Water Reactor
5. Curie (Ci): A measure of radioactivity; equal to 3.7E+10 disintegrations per second, or 2.22E+12 disintegrations per minute.
6. Direct Radiation Monitoring: The measurement of radiation dose at various distances from the plant is assessed using thermoluminescent dosimeters (TLDs), optically stimulated luminescent dosimeters (OSLDs), and/or pressurized ionization chambers.
7. EPRI: Electric Power Research Institute
8. Ingestion Pathway: The ingestion pathway includes milk, fish, and garden produce. Meat or other food products may also be included.
9. ISFSI: Independent Spent Fuel Storage Installation
10. Lower Limit of Detection (LLD): The smallest concentration of radioactive material in a sample that will yield a net count (above system background) that will be detected with 95% probability with a 5% probability of a false conclusion that a blank observation represents "real" signal.
11. Microcurie (µCi): 3.7E+10 disintegrations per second, or 2.22E+06 disintegrations per minute.
12. millirem (mrem): 1/1000 rem; a unit of radiation dose equivalent in tissue.

13. NA: Not Applicable
14. NEI: Nuclear Energy Institute
15. NRC: Nuclear Regulatory Commission
16. ODCM: Offsite Dose Calculation Manual
17. pCi: is equal to one trillionth of a curie
18. PNPP: Perry Nuclear Power Point
19. PWR: Pressurized Water Reactor
20. RETS: Radiological Effluent Technical Specifications
21. REMP: Radiological Environmental Monitoring Program
22. Restricted Area: Any area where access is controlled for the purpose of protecting individuals from exposure to radiation or radioactive materials.
23. TLD: Thermoluminescent Dosimeter
24. TS: Technical Specification

1.0 EXECUTIVE SUMMARY

Perry Nuclear Power Plant (PNPP) Radiological Effluent Technical Specifications (RETS) Program was established to limit the quantities of radioactive material that may be released based on calculated radiation doses or dose rates. Dose to Members of the Public due to radioactive materials released from the plant is limited by Appendix I of 10 CFR 50 and by 40 CFR 190. Operational doses to the public during 2021 were calculated to be very small compared to the limits required by regulation and pose no health hazard when compared to other sources of radiation dose.

The Annual Radioactive Effluent Release Report (ARERR) details the results of the effluent monitoring program conducted at the Perry Nuclear Power Plant (PNPP) from January 01 through December 31, 2021. This report meets all the requirements in PNPP Technical Specifications, the Offsite Dose Calculation Manual (ODCM), and Regulatory Guide 1.21.

In addition to monitoring radioactive effluents, PNPP has a Radiological Environmental Monitoring Program (REMP) that monitors for buildup of radioactivity in the offsite environment. Data from the REMP is published in the Annual Radiological Environmental Operating Report (AREOR).

1.1 <u>Radioactive Effluent Releases</u>

During the normal operation of a nuclear power plant, small quantities of radioactivity are released to the environment through liquid and gaseous effluent pathways. Radioactive material is also shipped offsite as solid waste. PNPP maintains a comprehensive program to control and monitor the release of radioactive materials from the site in accordance with Nuclear Regulatory Commission (NRC) release regulations.

Dose to the general public from the plant’s liquid and gaseous effluent pathways were well below regulatory limits. The calculated maximum individual whole-body dose potentially received by an individual resulting from PNPP liquid effluents was 4.43E-02 mrem (1.5E+00 percent of the regulatory limit). The calculated maximum individual whole-body dose potentially received by an individual resulting from PNPP gaseous effluents, excluding carbon-14 (C-14) was 1.28E-05 mrem (2.6E-04 percent of the regulatory limit).

Radioactivity released to the environment in the form of gaseous C-14 was estimated based on plant type and power production. The calculation is based on an industry initiative supported by the Nuclear Energy Institute (NEI), the Electric Power Research Institute (EPRI), and the NRC. The calculated hypothetical maximum annual individual whole-body dose potentially received by an individual resulting from PNPP gaseous effluents for C-14 is 2.52E-01 mrem/yr (5.0E+00 percent of the limit). Refer to Section 11 for additional C-14 information.

The summation of the hypothetical maximum individual dose from effluents is less than 1.0E+00 percent of the total dose an individual living in the PNPP area receives from all sources of man-made and background radiation.

Shipments of solid waste consisted of waste generated during water treatment, radioactive material generated during normal daily operations and maintenance, and irradiated components. PNPP complied with regulations governing radioactive shipments of solid radioactive waste.

2.0 INTRODUCTION

Nuclear energy provides an alternative energy source that is readily available with a very limited impact upon the environment. To more fully understand nuclear energy as a source of generating electricity, it is helpful to understand basic radiation concepts and the occurrence of radioactivity in nature.

2.1 About Nuclear Power

Commercial nuclear power plants are generally classified as either Boiling Water Reactors (BWRs) or Pressurized Water Reactors (PWRs), based on their design. A BWR includes a single coolant system where water used as reactor coolant boils as it passes through the core and the steam generated is used to turn the turbine generator for power production. A PWR, in contrast, includes two separate water systems: radioactive reactor coolant and a secondary system. Reactor coolant is maintained under high pressure, preventing boiling. The high-pressure coolant is passed through a heat exchanger called a steam generator where the secondary system water is boiled, and the steam is used to turn the turbine generator for power production.

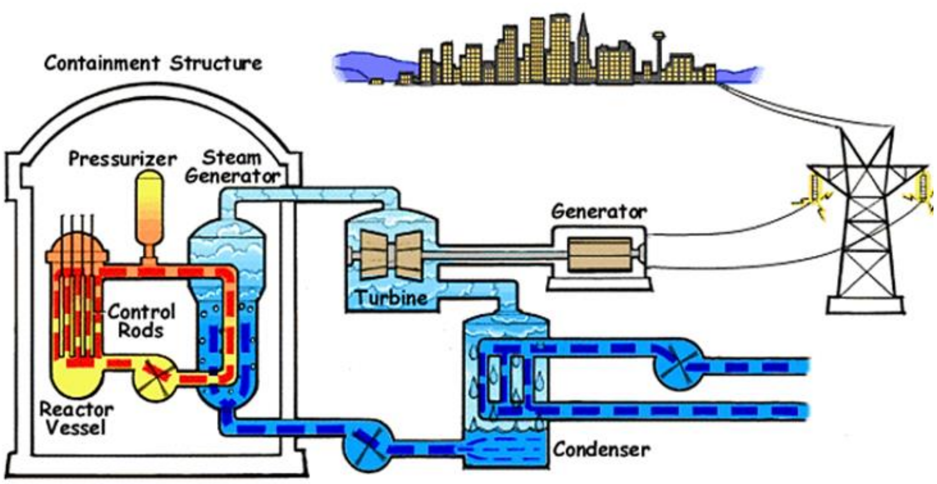

Figure 1, Pressurized Water Reactor (PWR) [1]

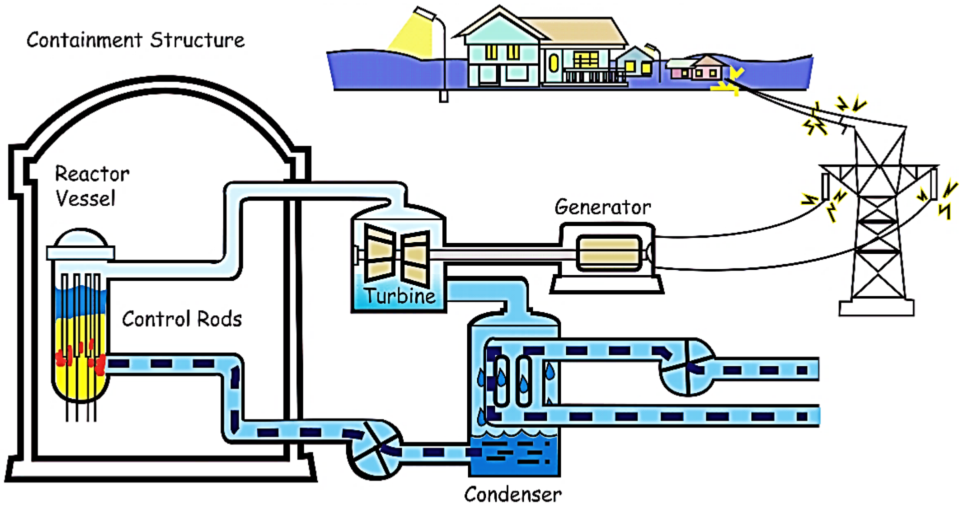

Figure 2, Boiling Water Reactor (BWR) [2]

Electricity is generated by a nuclear power plant similarly to the way that electricity is generated at other conventional types of power plants, such as those driven by coal or natural gas. Water is boiled to generate steam. The steam turns a turbine that is attached to a generator, and the steam is condensed back into water to be returned to the boiler. What makes nuclear power different from these other types of power plants is that heat is generated by fission and decay reactions occurring within and around the core containing fissionable uranium (U-235).

Nuclear fission occurs when certain nuclides (primarily U-233, U-235, and Pu-239) absorb a neutron and break into several smaller nuclides (called fission products) as well as some additional neutrons.

Fission results in production of radioactive materials including gases and solids that must be contained to prevent release or treated prior to release. These effluents are generally treated by filtration and/or hold-up prior to release. Releases are generally monitored by sampling and by continuously indicating radiation monitors. The effluent release data is used to calculate doses in order to ensure that dose to the public due to plant operation remains within required limits

2.2 About Radiation Dose

Ionizing radiation, including alpha, beta, and gamma radiation from radioactive decay, has enough energy to break chemical bonds in tissues and result in damage to tissue or genetic material. The amount of ionization that will be generated by a given exposure to ionizing radiation is quantified as dose. Radiation dose is generally reported in units of millirem (mrem) in the US.

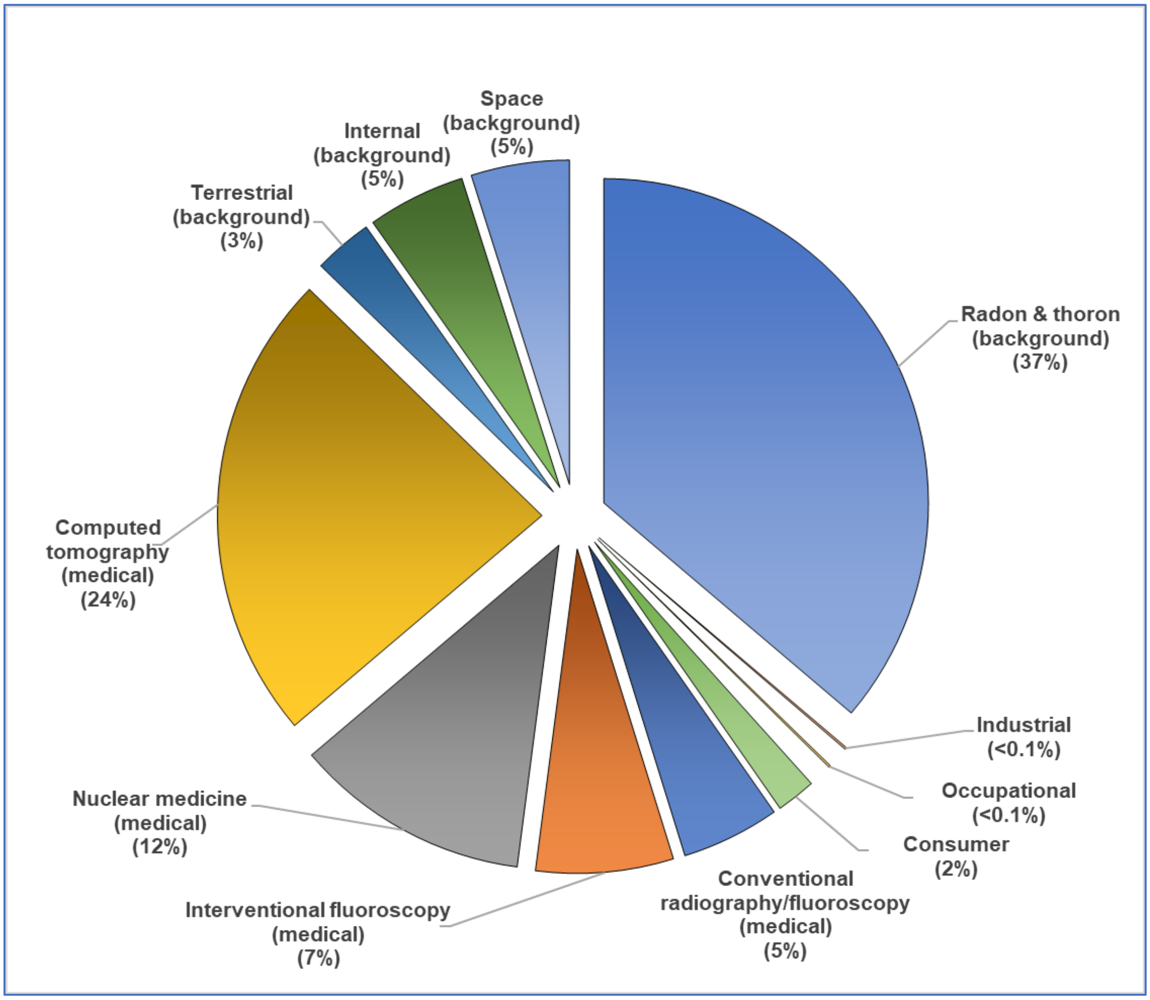

Figure 3, Sources of Radiation Exposure (NCRP Report No. 160) [3]

The National Council on Radiation Protection (NCRP) has evaluated the population dose for the US and determined that the average individual is exposed to approximately 620 mrem per year [3]. There are many sources for radiation dose, ranging from natural background sources to medical procedures, air travel, and industrial processes. Approximately half (310 mrem) of the average exposure is due to natural sources of radiation including exposure to Radon, cosmic radiation, and internal radiation and terrestrial due to naturally occurring radionuclides. The remaining 310 mrem of exposure is due to man-made sources of exposure, with the most significant contributors being medical (48%) due to radiation used in various types of medical scans and treatments. Of the remaining 2% of dose, most is due to consumer activities such as air travel, smoking cigarettes, and building materials. A small fraction of this 2% is due to industrial activities including generation of nuclear power.

Readers that are curious about common sources and effects of radiation dose that they may encounter can find excellent sources of information from the Health Physics Society, including the Radiation Fact Sheets [4], and from the US Nuclear Regulatory Commission website [5].

Concentrations of radioactive material in the environment resulting from plant operations are very small and it is not possible to determine doses directly using measured activities of environmental samples. To overcome this, Dose Calculations based on measured activities of effluent streams are used to model the dose impact for Members of the Public due to plant operation and effluents. There are several mechanisms that can result in dose to members of the public, ingestion of radionuclides in food or water; inhalation of radionuclides in air, immersion in a plume of noble gases, and direct radiation from the ground, the plant or from an elevated plume.

2.3 Lower Limit of Detection

Sample results are often reported as below the Lower Limit of Detection (LLD). The LLD for an analysis is the smallest amount of radioactive material that will show a positive result, for which there can be a 95% confidence that radioactivity is present. This statistical parameter is used as a measure of the sensitivity of a sample analysis. When a measurement is reported as less than the LLD (<LLD), it means that no radioactivity was detected. Had radioactivity been present at or above the stated LLD value, it statistically would have been detected. The NRC has established the required LLD values for environmental and effluent sample analyses.

For liquid releases, dilution and mixing factors are used to model the environmental concentrations in water. Drinking water pathways are modeled by determining the concentration of nuclides in the water at the point where the drinking water is sourced. Fish and invertebrate pathways are determined by using concentration at the release point, bioaccumulation factors for the fish or invertebrate and an estimate of the quantity of fish consumed.

Each year a Land Use Census is performed to determine what potential dose pathways currently exist within a five-mile radius around the plant, the area most affected by plant operations. The Annual Land Use Census identifies the locations of vegetable gardens, nearest residences, milk animals, and meat animals. The data from the census is used to determine who is the likely to be most exposed to radiation dose as a result of plant operation.

There is significant uncertainty in dose calculation results, due to modeling dispersion of material released and bioaccumulation factors, as well as assumptions associated with consumption and land-use patterns. Even with these sources of uncertainty, the calculations do provide a reasonable estimate of the order of magnitude of the exposure. Conservative assumptions are made in the calculation inputs such as the number of various foods and water consumed, the amount of air inhaled, and the amount of direct radiation exposure from the ground or plume, such that the actual dose received are likely lower than the calculated dose. Even with the built-in conservatism, doses calculated for the highest hypothetical exposed individual due to plant operation are a very small fraction of the annual dose that is received due to other sources. The low calculated doses due to the plant effluents, along with REMP

results indicating no detectible radioactive material due to plant operations, serve to provide assurance that the site is not having a negative impact on the environment or people living near the plant.

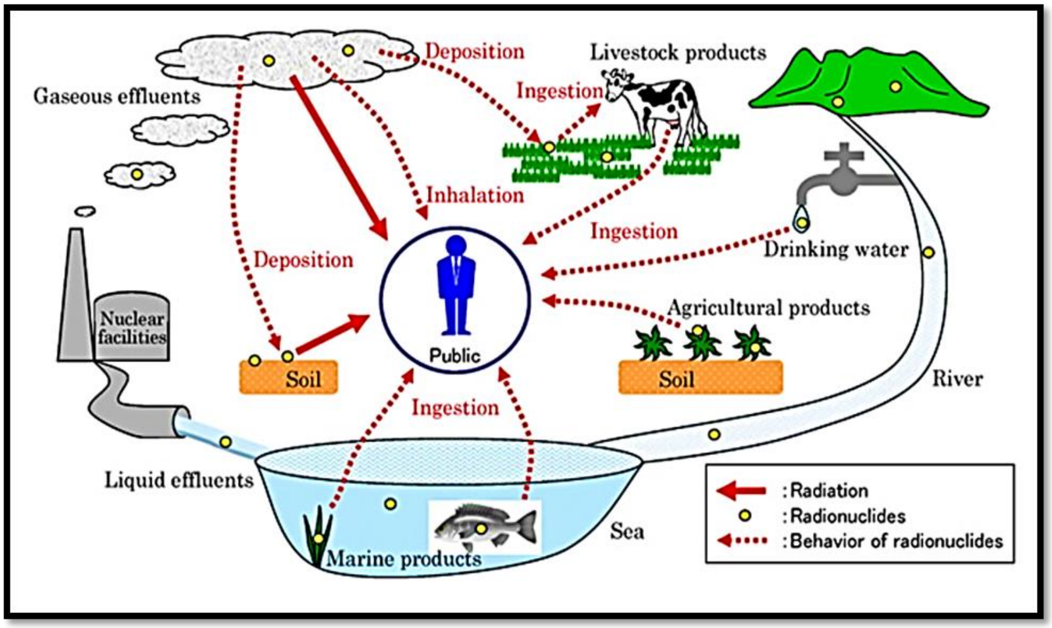

Figure 4, Potential exposure pathways to Members of the Public due to Plant Operations [6]

The Offsite Dose Calculation Manual (ODCM) specifies the methodology used to obtain the doses in the Dose Assessment section of this report. The methodology in the ODCM is based on NRC Regulatory Guide 1.109 [7] and NUREG-0133 [8]. Doses are calculated by determining what the nuclide concentration will be in air, water, on the ground, or in food products based on plant effluent releases. Release points are continuously monitored to quantify what concentrations of nuclides are being released. For gaseous releases meteorological data is used to determine how much of the released activity will be present at a given location outside of the plant either deposited onto the ground or in gaseous form. Intake patterns and nuclide bio-concentration factors are used to determine how much activity will be transferred into animal milk or meat. Finally, human ingestion factors and dose factors are used to determine how much activity will be consumed and how much dose the consumer will receive. Inhalation dose is calculated by determining the concentration of nuclides and how much air is breathed by the individual.

3.0 Radioactive Effluent Releases

3.1 Introduction

The source of radioactive material in a nuclear power plant is the generation of fission products (e.g., noble gas, iodine, and particulate) or neutron activation of water and corrosion products (e.g., tritium and cobalt). The majority of the fission products generated remain within the nuclear fuel pellet and fuel cladding. Most fission products that escape from the fuel cladding, as well as the majority of the activated corrosion products, are removed by plant processing equipment.

During the normal operation of a nuclear power plant, small amounts of radioactive material are released in the form of solids, liquids, and gases. PNPP was designed and is operated in such a manner as to control and monitor these effluent releases. Effluents are controlled to ensure any radioactivity released to the environment is minimal and within regulatory limits. Effluent release programs include the operation of monitoring systems, in-plant sampling and analysis, quality assurance, and detailed procedures covering all aspects of effluent monitoring.

The liquid and gaseous radioactive waste treatment systems at PNPP are designed to collect and process these wastes in order to remove most of the radioactivity. Effluent monitoring systems are used to provide continuous indication of the radioactivity present and are sensitive enough to measure several orders of magnitude lower than the release limits. This monitoring instrumentation is equipped with alarms and indicators in the plant control room. The alarms are set to provide warnings to alert plant operators when radioactivity levels reach a small fraction of the limits. The waste streams are sampled and analyzed to identify and quantify the radionuclides being released to the environment.

Gaseous effluent release data is coupled with on-site meteorological data in order to calculate the dose to the general public. Devices are maintained at various locations around PNPP to continuously sample the air in the surrounding environment. Frequent samples of other environmental media are also taken to determine if any radioactive material deposition has occurred.

Generation of solid waste is controlled to identify opportunities for minimization. Limiting the amount of material taken into the plant and sorting material as radioactive or non-radioactive waste helps to lower the volume of radioactive solid waste generated. After vendor processing, solid waste is shipped to a licensed burial site.

3.2 Regulatory Limits

The Nuclear Regulatory Commission has established limits for liquid and gaseous effluents that comply with:

> 10 CFR 20: Title 10 of the Code of Federal Regulations, Part 20, Standards for Protection Against Radiation, Appendix B;
>
> 10 CFR 50: Title 10 of the Code of Federal Regulations, Part 50, Domestic Licensing of Production and Utilization Facilities, Appendix I;

10 CFR 72.104: Title 10 of the Code of Federal Regulations, Part 72.104, Criteria for Radioactive Materials in Effluents and Direct Radiation from an ISFSI or MRS

40 CFR 190: Title 40 of the Code of Federal Regulations, Part 190, Environmental Radiation Protection Standards for Nuclear Power Operations

These limits were incorporated into the PNPP Technical Specifications, and subsequently into the PNPP ODCM. The ODCM prescribes the maximum doses and dose rates due to radioactive effluents resulting from the operation of PNPP. These limits are defined in several ways and serve to limit the overall impact on persons living near the plant. Since there are no other fuel sources near the PNPP, the 40 CFR 190 limits described below were not exceeded.

3.2.1 Liquid Effluents

The concentration of radioactive material released in liquid effluents to unrestricted areas shall be limited to the concentrations specified in 10 CFR 20, Appendix B, Table 2, Column 2 for radionuclides other than dissolved or entrained noble gases, as required by the ODCM. For dissolved or entrained noble gases, the concentration is limited to 2.0E-04 µCi/ml. These values are the maximum effluent concentrations.

The dose or dose commitment to a member of the public from radioactive materials in liquid effluents released to unrestricted areas shall be limited to the following:

During any calendar quarter:
Less than or equal to 1.5 mrem to the whole body, and
Less than or equal to 5 mrem to any organ

During any calendar year:
Less than or equal to 3 mrem to the whole body, and
Less than or equal to 10 mrem to any organ

3.2.2 Gaseous Effluents

The dose rate due to radioactive materials released in gaseous effluents (including any releases from the on-site ISFSI) from the site to areas at and beyond the site boundary are governed by 10 CFR 20 and shall be limited to the following as required by the PNPP ODCM:

- Noble gases:
  Less than or equal to 500 mrem per year to the whole body, and
  Less than or equal to 3000 mrem per year to the skin

- Iodine-131, iodine-133, tritium, and all radionuclides in particulate form with half-lives greater than eight days:
  Less than or equal to 1500 mrem per year to any organ

Air dose due to noble gases to areas at and beyond the site boundary are governed by 10 CFR 50 Appendix I and shall be limited to the following:

- During any calendar quarter:
  Less than or equal to 5 mrad for gamma radiation, and
  Less than or equal to 10 mrad for beta radiation
- During any calendar year:
  Less than or equal to 10 mrad for gamma radiation, and
  Less than or equal to 20 mrad for beta radiation

Dose to a member of the public from iodine-131, iodine-133, tritium, and all radionuclides in particulate form with half-lives greater than eight days in gaseous effluents released to areas at and beyond the site boundary shall be limited to the following:

Less than or equal to 7.5 mrem to any organ per any calendar quarter, and
Less than or equal to 15 mrem to any organ per any calendar year

The PNPP ODCM does not contain a concentration limit for gaseous effluents. For this reason, effluent concentrations are not used to calculate maximum release rates for gaseous effluents.

3.3 Release Summary

Effluents are sampled and analyzed to identify both the type and quantity of radionuclides present. This information is combined with effluent path flow measurements to determine the composition, concentration, and dose contribution of the radioactive effluents.

3.4 40CFR190 and 10CFR72.104 – Uranium Fuel Cycle Dose Assessment

The 40 CFR 190 limit for whole body dose is 25 mrem. Considering all sectors, the total whole-body dose to a member of the general public was 0.296 mrem. This value was determined by summing the annual whole-body doses from liquid and gaseous radioactive effluents and the annual gaseous C-14 dose. Since the direct radiation dose, as determined by TLD, was indistinguishable from natural background, it was not included in the calculation. More information regarding direct radiation dose and the Independent Spent Fuel Storage Installation (ISFSI), may be found on page 14.

3.5 Independent Spent Fuel Storage Installation (ISFSI)

Dose rates from the ISFSI contributing to a dose to a member of the public at or beyond the site boundary is governed by 10 CFR 72.104 and shall be limited to the following as required by the PNPP ODCM during any calendar year:

Less than or equal to 25 mrem whole body dose;
Less than or equal to 75 mrem thyroid dose; and
Less than or equal to 25 mrem to any other critical organ.

3.5.1 10CFR72.104, ISFSI Compliance

Since installation of the Independent Spent Fuel Storage Installation (ISFSI) in 2011, eight TLDs have been placed on the outer perimeter fence of the cask storage area (located within the site boundary) to monitor dose due to direct radiation from the spent fuel stored on the ISFSI.

Since the dosimeters measure an accumulation of all sources of radiation, the following justification was used to determine how to most accurately calculate the dose received to the nearest resident contributed only by the spent fuel at the ISFSI.

To determine the dose contributed by the spent fuel only, one would need to discriminate out the dose associated with background radiation as described above and other sources. Dosimeters close to the plant are susceptible to "shine" which is radiation from nitrogen-16 that is reflected by the atmosphere. Background radiation and shine affect the surrounding TLDs almost uniformly.

The dosimeters closest to the dry casks receive more dose from the spent fuel and are thus affected by a lesser percentage by background radiation and plant effluents than those further away. To more accurately calculate the dose contribution to the nearest resident from the spent fuel, the dosimeter nearest to the point source is used.

The dose calculation was performed using the location of the nearest residence, assuming they remain at the location all year, because that individual would incur the maximum potential dose from direct exposure. The TLD at REMP location 7 found in the AREOR is positioned neighboring the nearest resident, was also reviewed for significant changes in readings.

To determine the dose rate to the nearest resident and demonstrate compliance, the following equation was used:

$$D_1R_1^2=D_2R_2^2$$

Where:

D_1 = dose rates (mrem/yr) at the TLD location
D_2 = dose rates (mrem/yr) to nearest resident
R_1 = distance (feet) of nearest TLD location to max individual
R_2 = distance (feet) to nearest resident

The two nearest TLDs were chosen to estimate dose rates, which were #15 and #20, directly east and west of the dry casks. The corresponding estimated dose rates to the nearest resident was 2.11E-01 and 2.25E-01 mrem/yr, respectively, in 2021. In 2020, the calculated values were slightly lower, but statistically comparable to results of 2021. Unlike the whole body dose value of 2.96E-01 mrem presented on page 13, the dose rates of 2.11E-01 and 2.25E-01 mrem/yr are an estimate based on TLD readings to demonstrate compliance. The calculation confirms that direct dose from the ISFSI does not exceed the 40 CFR 190 limit of 25 mrem/year.

Review of the TLD results from 2021 have shown no detectable impact on dose to the public due to radiation from the ISFSI nor significant changes in results to the public since employment of the ISFSI.

4.0 Liquid Effluents

The PNPP liquid radioactive waste system is designed to collect and treat all radioactive liquid waste produced in the plant. The treatment process used for radioactive liquid waste depends on its physical and chemical properties. It is designed to reduce the concentration of radioactive material in the liquid by filtration to remove suspended solids and demineralization to remove dissolved solids. Normally, the effluent from the liquid radioactive waste system is returned to plant systems. To reduce the volume of water stored in plant systems, however, the processed liquid effluents may be discharged from the plant via a controlled release. In this case, effluent activity and dose calculations are performed prior to and after discharging this processed water to Lake Erie to ensure regulatory compliance and dose minimization principles are maintained.

Liquid radioactive waste system effluents may be intermittently released, which are considered to be "batch" releases. Table 1 provides information on the number and duration of these releases for 2021.

Table 1: Liquid Batch Releases

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Number of batch releases	5	14	0	1
Total time period for batch releases, min	1.56E+03	3.82E+03	0.00E+00	2.59E+02
Maximum time for a batch release, min	6.09E+02	7.18E+02	0.00E+00	2.59E+02
Average time period for a batch release, min	3.11E+02	2.73E+02	0.00E+00	2.59E+02
Minimum time for a batch release, min	9.00E+01	2.22E+02	0.00E+00	2.59E+02
Average quarterly flow rate, L/min	6.87E+04	1.56E+05	0.00E+00	3.79E+00

Table 2 provides information on the nuclide composition for the liquid radioactive effluent system releases. In each case, LLDs were at or below the required values. Table 2a provides information specific to radioactive effluent batch releases and Table 2b provides information specific to continuous radioactive effluent releases. A batch release is the discharge of liquid waste of a discrete volume. Potential sources for a batch release at Perry are Liquid Radwaste Discharges via the Emergency Service Water system and auxiliary steam tritium in-leakage to the Auxiliary Boiler vented into the atmosphere. A continuous release is the discharge of fluid wastes of a non-discrete volume. Potential sources for a continuous release at Perry are Residual Heat Removal (RHR) heat exchanger leakage into the Emergency Service Water system, Nuclear Closed Cooling (NCC) out-leakage into the Service Water system, tritium activity in the Turbine Building Ventilation (M35) Supply Plenum drain into storm drains, and Alternate Decay Heat Removal (ADHR) heat exchanger leakage into Service Water.

Table 2: Summation of All Liquid Effluent Releases

	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Uncertainty (%)
A. Fission and Activation Products					
1. Total Released, Ci (excluding tritium, gases, alpha)	**5.14E-04**	**8.44E-03**	**1.78E-05**	**1.69E-04**	**1.00E+01**
2 Average Diluted Concentration, µCi/mL *	2.23E-11	3.8E-10	6.63E-13	7.46E-12	
3. Percent of Applicable Limit, %	6.40E-04	9.96E-03	6.63E-07	7.46E-06	
B. Tritium					
1. Total Released, Ci	**8.50E-01**	**4.19E+00**	**9.43E-03**	**3.59E-03**	**1.00E+01**
2. Average Diluted Concentration, µCi/mL	3.69E-08	1.89E-07	3.51E-10	1.58E-10	
3. Percent of Applicable Limit, %	3.69E-03	1.89E-02	3.51E-05	1.58E-05	
C. Dissolved and Entrained Gases					
1. Total Released, Ci	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**1.00E+01**
2. Average Diluted Concentration, µCi/mL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
3. Percent of Applicable Limit, %	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
D. Gross Alpha Activity, Ci	**1.19E-07**	**2.86E-07**	**8.49E-06**	**0.00E+00**	**1.00E+01**
E. Waste Volume Released, Liters (prior to dilution)*	2.99E+07	5.59E+08	1.53E+06	2.40E+06	
F. Dilution Water Volume Used, Liters	2.30E+10	2.22E+10	2.69E+10	2.27E+10	

*Average diluted concentrations are based on total volume of water released during quarter.

Table 2a: Summation of Batch Liquid Effluent Releases

	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Uncertainty (%)
A. Fission and Activation Products					
Total Released, Ci (excluding tritium, gases, alpha)	5.14E-04	8.44E-03	0.00E+00	0.00E+00	1.00E+01
B. Tritium					
Total Released, Ci	8.50E-01	4.19E+00	0.00E+00	1.64E-03	1.00E+01
C. Dissolved and Entrained Gases					
Total Released, Ci	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+01
D. Gross Alpha Activity, Ci	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+01
E. Waste Volume Released, Liters (prior to dilution)*	4.21E+05	2.34E+06	0.00E+00	6.41E+03	

<LLD – Less than the lower limit of detection

*Average diluted concentrations are based on total volume of water released during quarter.

Table 2b: Summation of Continuous Liquid Effluent Releases

	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Uncertainy (%)
A. Fission and Activation Products					
Total Released, Ci (excluding tritium, gases, alpha)	0.00E+00	0.00E+00	1.78E-05	1.69E-04	1.00E+01
B. Tritium					
Total Released, Ci	2.83E-07	7.94E-04	9.43E-04	1.95E-03	1.00E+01
C. Dissolved and Entrained Gases					
Total Released, Ci	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+01
D. Gross Alpha Activity, Ci	1.19E-07	2.86E-07	8.49E-06	0.00E+00	1.00E+01
E. Waste Volume Released, Liters (prior to dilution)*	2.95E+07	5.56E+08	1.53E+06	2.39E+06	

<LLD – Less than the lower limit of detection

*Average diluted concentrations are based on total volume of water released during quarter.

Table 3 lists the total number of curies of each radionuclide present in liquid effluent releases for each quarter. In each case, the LLDs were either met or were below the levels required by the ODCM.

Table 3: Radioactive Liquid Effluent Nuclide Composition

Isotope	Unit	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Annual
Tritium	Ci	8.50E-01	4.19E+00	9.43E-04	3.59E-03	5.05E+00
Sodium-24	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Manganese-54	Ci	2.63E-05	6.46E-04	<5.0E-07 [1]	<5.0E-07 [1]	6.72E-04
Iron-55	Ci	<1.0E-06 [1]	<1.0E-06 [1]	<1.0E-06 [1]	<1.0E-06 [1]	<1.0E-06 [1]
Manganese-56	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Cobalt-58	Ci	4.63E-05	5.31E-04	<5.0E-07 [1]	<5.0E-07 [1]	5.77E-04
Iron-59	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Cobalt-60	Ci	4.23E-04	5.22E-03	<5.0E-07 [1]	<5.0E-07 [1]	5.64E-03
Nickel-63	Ci	<1.0E-06 [1]	<1.0E-06 [1]	1.78E-05	1.69E-04	1.87E-04
Zinc-65	Ci	<5.0E-07 [1]	3.10E-04	<5.0E-07 [1]	<5.0E-07 [1]	3.10E-04
Zinc-69m	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Strontium-89	Ci	<5.0E-08 [1]	<5.0E-08 [1]	<5.0E-08 [1]	<5.0E-08 [1]	<5.0E-08 [1]
Strontium-90	Ci	<5.0E-08 [1]	<5.0E-08 [1]	<5.0E-08 [1]	<5.0E-08 [1]	<5.0E-08 [1]
Strontium-91	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Yttrium-91m	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Strontium-92	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Molybdenum-99	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Technetium-99m	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Silver-110m	Ci	1.83E-05	3.24E-05	<5.0E-07 [1]	<5.0E-07 [1]	5.07E-05
Tin-113	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Antimony-124	Ci	<5.0E-07 [1]	6.35E-04	<5.0E-07 [1]	<5.0E-07 [1]	6.35E-04
Antimony-125	Ci	<5.0E-07 [1]	9.04E-04	<5.0E-07 [1]	<5.0E-07 [1]	9.04E-04
Cesium-137	Ci	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]	<5.0E-07 [1]
Iodine-131	Ci	<1.0E-06 [1]	1.64E-04	<1.0E-06 [1]	<1.0E-06 [1]	1.64E-04
Cerium-144	Ci	<5.0E-06 [1]	<5.0E-06 [1]	<5.0E-06 [1]	<5.0E-06 [1]	<5.0E-06 [1]
Xenon-133	Ci	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]
Xenon-135	Ci	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]
Gross Alpha	Ci	1.19E-07	2.86E-07	8.49E-06	<1.0E-07 [1]	8.90E-06

1 – (<) Less than the ODCM-required lower limit of detection, units in µCi/mL

5.0 GASEOUS EFFLUENTS SUMMARY

Gaseous effluents are made up of fission and activation gases, iodine, and particulate releases. Gaseous effluents from PNPP exit the plant via one of four effluent vents. Each of these four effluent vents contains radiation detectors that continuously monitor the air to ensure that the levels of radioactivity released are below regulatory limits. Samples are also collected and analyzed on a periodic basis to ensure regulatory compliance. Gaseous effluents released from PNPP are considered continuous and at ground level. A summation of all gaseous radioactive effluent releases is given in Table 4.

Table 4: Summation of All Gaseous Effluents

	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Uncertainty (%)
A. Fission and Activation Gases					
1. Total Released, Ci	**2.82E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.00E+01
2. Average Release Rate, µCi/sec	3.63E-01	0.00E+00	0.00E+00	0.00E+00	
3. Percent of Applicable Limit, %	N/A	N/A	N/A	N/A	
B. Iodine					
1. Total Iodine-131 Released, Ci	**1.32E-05**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.00E+01
2. Average Release Rate, µCi/sec	1.70E-06	0.00E+00	0.00E+00	0.00E+00	
3. Percent of Applicable Limit, %	N/A	N/A	N/A	N/A	
C. Particulates with Half-Lives > 8 days					
1. Total Released, Ci	**7.16E-06**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.00E+01
2. Average Release Rate, µCi/sec	9.21E-07	0.00E+00	0.00E+00	0.00E+00	
3. Percent of Applicable Limit, %	N/A	N/A	N/A	N/A	
4. Alpha Activity, Ci	**2.84E-06**	**2.45E-06**	**2.71E-06**	**2.91E-06**	
D. Tritium					
1. Total Released, Ci	**2.03E+00**	**9.13E-01**	**1.83E+00**	**3.53E+00**	1.00E+01
2. Average Release Rate, µCi/sec	2.61E-01	1.16E-01	2.31E-01	4.44E-01	
3. Percent of Applicable Limit, %	N/A	N/A	N/A	N/A	
E. Carbon-14, Ci	**2.98E+00**	**4.25E+00**	**4.70E+00**	**4.73E+00**	1.00E+01

N/A – Not Applicable, the ODCM does not have a release rate limit for gaseous effluents
Carbon-14 activity was calculated based on power production using the EPRI-provided spreadsheet

The radionuclide composition of all gaseous radioactive effluents for a continuous-mode, ground-level release is given in Table 5. In each case, LLDs were met or were below the levels required by the ODCM.

Table 5: Radioactive Gaseous Effluent Nuclide Composition

Isotope	Unit	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Annual
1. Fission and Activation Gases						
Tritium	Ci	2.03E+00	9.13E-01	1.83E+00	3.53E+00	8.30E+00
Argon-41	Ci	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]
Krypton-85m	Ci	5.38E-01	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	5.38E-01
Krypton-87	Ci	9.97E-03	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	9.97E-03
Krypton-88	Ci	1.81E-02	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	1.81E-02
Xenon-133m	Ci	3.79E-02	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	3.79E-02
Xenon-133	Ci	1.52E+00	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	1.52E+00
Xenon-135m	Ci	1.46E-01	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	1.46E-01
Xenon-135	Ci	5.55E-01	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	5.55E-01
Xenon-138	Ci	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]	<1.0E-04 [1]
Total for Period	Ci	4.85E+00	9.13E-01	1.83E+00	3.53E+00	1.11E+01
2. Iodine/Halogens						
Iodine-131	Ci	1.32E-05	<1.0E-12 [1]	<1.0E-12 [1]	<1.0E-12 [1]	1.32E-05
Iodine-133	Ci	1.26E-05	<1.0E-10 [1]	<1.0E-10 [1]	<1.0E-10 [1]	1.26E-05
Total for Period	Ci	2.58E-05	<LLD	<LLD	<LLD	2.58E-05
3. Particulates						
Chromium-51	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Manganese-54	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Iron-59	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Cobalt-58	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Cobalt-60	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Zinc-65	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Strontium-89	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Molybdenum-99	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Cesium-137	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Cerium-141	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Cerium-144	Ci	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]	<1.0E-11 [1]
Total for Period	Ci	7.16E-06	<LLD	<LLD	<LLD	<LLD

1 – (<) Less than the ODCM-required lower limit of detection, units in µCi/mL

<LLD – Less than the ODCM-required lower limit of detection

5.1.1 Solid Waste

All solid radioactive waste from PNPP was processed and combined with waste from several other utilities by intermediate vendors. The final waste after processing is sent to Energy Solutions' disposal facility in Clive, Utah for burial.

Table 6: Solid Waste Shipped Offsite for Burial or Disposal

1. Type of Solid Waste Shipped	Volume (m^3)	Activity (Ci)	Uncertainty (%)
a. Resins, Filters, and Evaporator Bottoms	9.47E+01	1.28E+02	± 25
b. Dry Radioactive Waste	4.84E+02	3.93E+00	± 25
c. Irradiated Components	0.00E+00	0.00E+00	± 25
d. Other Radioactive Waste	0.00E+00	0.00E+00	± 25

2. Estimate of Major (1) Nuclide Composition (by type of waste)	Radionuclide	Abundance (%)	Uncertainty (%)
a. Resins, Filters and Evaporator Bottoms	Mn-54	3.40	± 25
	Fe-55	37.18	
	Co-60	54.56	
	Ni-63	1.76	
	Zn-65	1.61	
b. Dry Active Waste	Mn-54	3.11	± 25
	Fe-55	49.37	
	Co-60	44.16	
	Ni-63	1.01	
	Zn-65	1.02	
c. Irradiated Components, Control Rods, etc.	N/A	N/A	N/A
d. Other Waste	N/A	N/A	N/A

(1) – "Major" is defined as any individual radionuclide identified as >1% of the waste type abundance.

N/A – Not applicable due to no shipments

3. Irradiated Fuel Shipments		
Number of Shipments	Mode of Transportation	Destination
30	Hittman Transport	Energy Solutions Bear Creek Operations
5	Hittman Transport	Erwin Resin Solutions, LLC 151 T.C Runnion Road
1	Speciality Transport Inc.	Energy Solutions Bear Creek Operations

5.2 Land Use Census Changes

In order to estimate radiation dose attributable to operation of the PNPP, the potential pathways through which public exposure can occur must be known. To identify these pathways, an Annual Land Use Census is performed as part of the REMP. During the census, PNPP personnel travel public roads within a five-mile radius of the plant to locate key radiological exposure pathways. These key pathways include the nearest resident, garden, in each of the ten meteorological land sectors that surround the plant. The information obtained from the census is entered into a computer program used to assess hypothetical dose to members of the public. The predominant land use within the census area continues to be rural and/or agricultural. There were no changes to the REMP sampling locations compared to the 2020 Land Use Census.

5.3 Meteorological Data

The Meteorological Monitoring System at PNPP consists of a 60-meter tower equipped with two independent systems for measuring wind speed, wind direction, and temperature at both 10-meter and 60-meter heights. The tower also has instrumentation to measure dew point and barometric pressure. Data is logged from the tower through separate data loggers and transmitted to a common plant computer. The program compiles the data and calculates a variety of atmospheric parameters, communicates with the Meteorological Information Dose Assessment System (MIDAS) and sends data over communication links to the plant Control Room.

A detailed report of the monthly and annual operation of the PNPP Meteorological Monitoring Program is produced as a separate document that is retained in PNPP Records and is available upon request. The report substantiates the quality and quantity of meteorological data collected in accordance with applicable regulatory guidance.

5.4 Dose Assessment

The maximum concentration for any radioactive release is controlled by the limits set forth in 10 CFR 20. Sampling, analyzing, processing, and monitoring the effluent streams ensures compliance with these concentration limits. Dose limit compliance is verified through periodic dose assessment calculations. Some dose calculations are conservatively performed for a hypothetical maximum individual who is assumed to reside on the site boundary at the highest potential dose location all year. This person, called the “maximum individual”, would incur the maximum potential dose from direct exposure (air plus ground plus water), inhalation, and ingestion of water, vegetation, and fish. Because no individual actually meets these criteria, the actual dose received by a real member of the public is significantly less than what is calculated for this hypothetical individual.

Dose calculations for this maximum individual at the site boundary are performed for two cases:

- Using data for a 360-degree radius around the plant site (land and water-based meteorological sectors); even though some of these sectors are over Lake Erie, which has no permanent residents;

- Considering only those sectors around the plant in which people reside (land-based meteorological sectors).

The calculated hypothetical, maximum individual dose values at the site boundary are provided in Table 7. This table considers all meteorological sectors around PNPP and provides whole body and worst-case organ-dose values.

Table 7: Maximum Yearly Individual Site Boundary Dose, Considering All Sectors

Type of Dose	Organ	Estimated Dose, (mrem)	Limit (mrem)	% of Limit
Liquid Effluent	Whole body	4.43E-02	3	1.5E+00
	Bone	7.61E-01	10	7.6E+00
Noble Gas	Air Dose Gamma (mrad)	3.47E-01	10	3.5E+00
	Air Dose Beta (mrad)	5.55E-01	20	2.8E+00
Noble Gas	Whole body	1.28E-05	5	2.6E-04
	Skin	3.52E-05	15	2.3E-04
Tritium, Particulate & Iodine	Thyroid	2.93E-04	15	2.0E-03
Carbon-14 *	Whole Body	2.52E-01	5	5.0E+00

*C-14 dose calculated at nearest garden.

The hypothetical maximum dose within a 50-mile radius of site was calculated and is presented in Table 8. This table considers all meteorological sectors around PNPP and provides whole body and worst-case organ dose values.

Table 8: Population Yearly Dose, Considering All Sectors out to 50 miles

	Organ	Estimated Dose (person-rem)
Liquid Effluent	Whole body	6.6E+00
	Thyroid	2.7E+00
Gaseous Effluent	Whole body	1.1E-03
	Thyroid	1.1E-03

Table 9 provides the calculated hypothetical maximum site boundary dose values considering only the land-based sectors.

Table 9: Maximum Yearly Individual Site Boundary Dose (Only Land Sectors)

Type of Dose	Organ	Estimated Dose, (mrem)	Limit (mrem)	% of Limit
Liquid Effluent	Whole Body	4.43E-02	3	1.5E+00
	Bone	7.61E-01	10	7.6E+00
Noble Gas	Air Dose Gamma (mrad)	3.47E-01	10	3.5E+00
	Air Dose Beta (mrad)	5.55E-01	20	2.8E+00
Noble Gas	Whole Body	1.28E-05	5	2.6E-04
	Skin	3.52E-05	15	2.3E-04
Tritium, Particulate & Iodine	Thyroid	2.93E-04	15	2.0E-03
Carbon-14 *	Whole Body	2.52E-01	5	5.0E+00

*C-14 dose calculated at nearest garden.

Other dose calculations are performed for a hypothetical individual assumed to be inside the site boundary for some specified amount of time. This person would receive the maximum dose during the time spent inside site boundary. Because no person actually meets the criteria established for these conservative calculations, the actual dose received by a member of the public is significantly less than what is calculated for this hypothetical individual. This dose is assessed relative to the offsite dose, and considers dilution, dispersion, and occupancy factors.

The highest hypothetical dose from liquid effluents to a member of the public inside the site boundary is to a person who is fishing on Lake Erie from the shore on PNPP property. The calculations assume that this person will spend 60 hours per year fishing, with a liquid dilution factor of 10. The ratio of the exposure pathway to the doses calculated for offsite locations yields the dose values shown in Table 10.

Table 10: Maximum Site Dose from Liquid Effluents

	Whole Body Dose, (mrem)	Organ Dose, (mrem)
First Quarter	8.7E-02	8.7E-02
Second Quarter	6.8E-03	8.7E-03
Third Quarter	2.2E-03	5.8E-02
Fourth Quarter	1.8E-01	4.7E+00
Annual	2.7E-01	4.7E+00

Although several cases were evaluated to determine the highest hypothetical dose from gaseous effluents to members of the public inside the site boundary, the activity inside the site boundary with the highest dose potential is also shoreline fishing. The cases evaluated included traversing a public road within the site boundary, shoreline fishing (assuming fishing 60 hours per year), non-plant related training, car-pooling, and job interviews. The maximum on-site gaseous doses generated are shown in Table 11.

Table 11: Maximum Site Dose from Gaseous Effluents

	Whole Body Dose, (mrem)	Organ Dose, (mrem)
First Quarter	5.35E-06	8.96E-06
Second Quarter	5.16E-06	5.16E-06
Third Quarter	1.60E-05	1.60E-05
Fourth Quarter	1.08E-05	1.08E-05
Annual	3.21E-05	3.53E-05

An average whole body dose to individual members of the public at or beyond the site boundary is then determined by combining the dose from gaseous and liquid radiological effluents. The dose from gaseous radiological effluents is based upon the population that lives within 50 miles of PNPP. The dose from liquid radiological effluents is determined for the population that receives drinking water from intakes within 50 miles of PNPP. The results of this calculation are provided in Table 12.

Table 12: Average Individual Whole-Body Dose

	Liquid Effluents, (mrem)	Gaseous Effluents, (mrem)
First Quarter	8.3E-04	1.1E-07
Second Quarter	8.3E-04	6.7E-08
Third Quarter	2.2E-05	1.3E-07
Fourth Quarter	1.8E-03	1.8E-07
Annual	2.8E-03	4.6E-07

6.0 Effluent Radiation Monitors Out of Service Greater Than 30 Days

On March 12, 2021 the Emergency Service Water (ESW) A Radiation Monitor became inoperable and stayed inoperable greater than 30 days. ODCM 3.3.7.9 Action b states, with less than the minimum number of radioactive liquid effluent monitoring instrumentation channels operable, take the action shown in Table 3.3.7.9-1. Restore the inoperable instrumentation to operable status within 30 days and, if unsuccessful, explain why this inoperability was not corrected in a timely manner in the next Annual Radioactive Effluent Release Report.

The ESW A Rad Monitor was investigated to determine why it was not functioning properly. PNPP's Fix It Now team worked to repair the ESW A radiation monitor. The pump was discovered to have failed, and a new pump was ordered and replaced once it arrived on site. ESW A radiation monitor was declared operable on April 30, 2021 at 13:35 following pump replacement and surveillance testing.

7.0 Offsite Dose Calculation Manual (ODCM) Changes

There were no changes to the ODCM.

8.0 Process Control Program (PCP) Changes

There were no changes to the PCP.

9.0 Radioactive Waste Treatment System Changes

There were no changes to the Radioactive Waste Treatment System.

10.0 Corrections to Previous ARERRs

This was the first year PNPP has implemented the ARERR. Previous years the Annual Environmental and Effluent Release Repot (AEERR) contained Perry's annual effluent releases. No corrections are needed to previous AEERRs.

11.0 Carbon-14 Supplemental Information

Carbon-14, with a half-life of 5730 years, is a naturally-occurring isotope of carbon produced by cosmic ray interactions in the atmosphere. Nuclear weapons testing in the 1950s and 1960s significantly increased the amount of C-14 in the atmosphere. Carbon-14 is also produced in commercial nuclear reactors, but the amounts produced are much less than those produced naturally or from weapons testing. It is released primarily from Boiling Water Reactors through the Off-gas system in the form of carbon dioxide (CO_2). The quantity of gaseous C-14 released to the environment can be estimated using a C-14 source term scaling factor based on power generation.

The U.S. Nuclear Regulatory Commission requires an assessment of gaseous C-14 dose impact to a member of the public resulting from routine releases in radiological effluents. Prior to 2011, the industry did not estimate the dose impact of C-14 releases because the dose contribution had been considered negligible compared to the dose impact from effluent releases of noble gases, tritium, particulates, and radioiodines.

This report contains estimates of the gaseous C-14 radioactivity released and the resulting public dose resulting from this release. The calculation is performed using a spreadsheet provided by EPRI and is based on power production and is adjusted for growing season, percent daylight, age (adult), and undepleted atmospheric dispersion (χ/Q) value for the critical receptor. This method for estimating C-14 released has been endorsed by the NRC. Because the dose contribution of C-14 from liquid radioactive waste is much less than that contributed by gaseous radioactive waste, evaluation of C-14 in liquid radioactive waste at PNPP is not required. Refer to Table 4, Table 7, and Table 9 for C-14 estimated release values and doses.

12.0 NEI 07-07 ONSITE RADIOLOGICAL GROUNDWATER MONITORING PROGRAM

Based on the Environmental Resource Management hydrogeology study,12 groundwater monitoring wells were recommended for the site. Since most groundwater flow drains north toward Lake Erie, the majority of wells are drilled north of the plant. A set of control wells were drilled south of the plant to assess a typical groundwater profile.

There are sets of three wells installed at four locations. Each set has a shallow well with a depth of approximately 25 feet, a mid-depth well with a depth of approximately 50 feet, and a deep-well of approximately 75 feet in depth. These three depths are designated A, B, and C, from shallowest to deepest, respectively.

More than 30 piezometers comprise the outdoor piezometers located in four separate transects oriented in the north, south, east, and west directions. These wells were installed to monitor the performance of the Underdrain System and ensure reduction in groundwater levels around the Power Block.

PNPP has an Underdrain system to prevent groundwater hydrostatic pressure buildup on plant structures. The Underdrain system has two installed radiation monitors that assess the process stream prior to the stream flowing into the Emergency Service Water system.

Refer to Figure 5 for locations of Groundwater Wells 1A through 4C, Outdoor Quadrant Piezometers north through south, and Underdrain Manholes 20 and 23. These wells, piezometers, and manholes encompass the groundwater monitoring locations at PNPP.

The monitoring wells and quadrant piezometers are sampled twice annually, in spring and fall. The samples are shipped to a vendor for gamma isotopic and tritium analysis. Any positive result less than 500 pCi/L is considered as background activity and not due to plant operations. The ODCM reporting level for tritium in an environmental water sample is 20,000 pCi/L. The tritium results of samples obtained in 2021 can be found in Table 13.

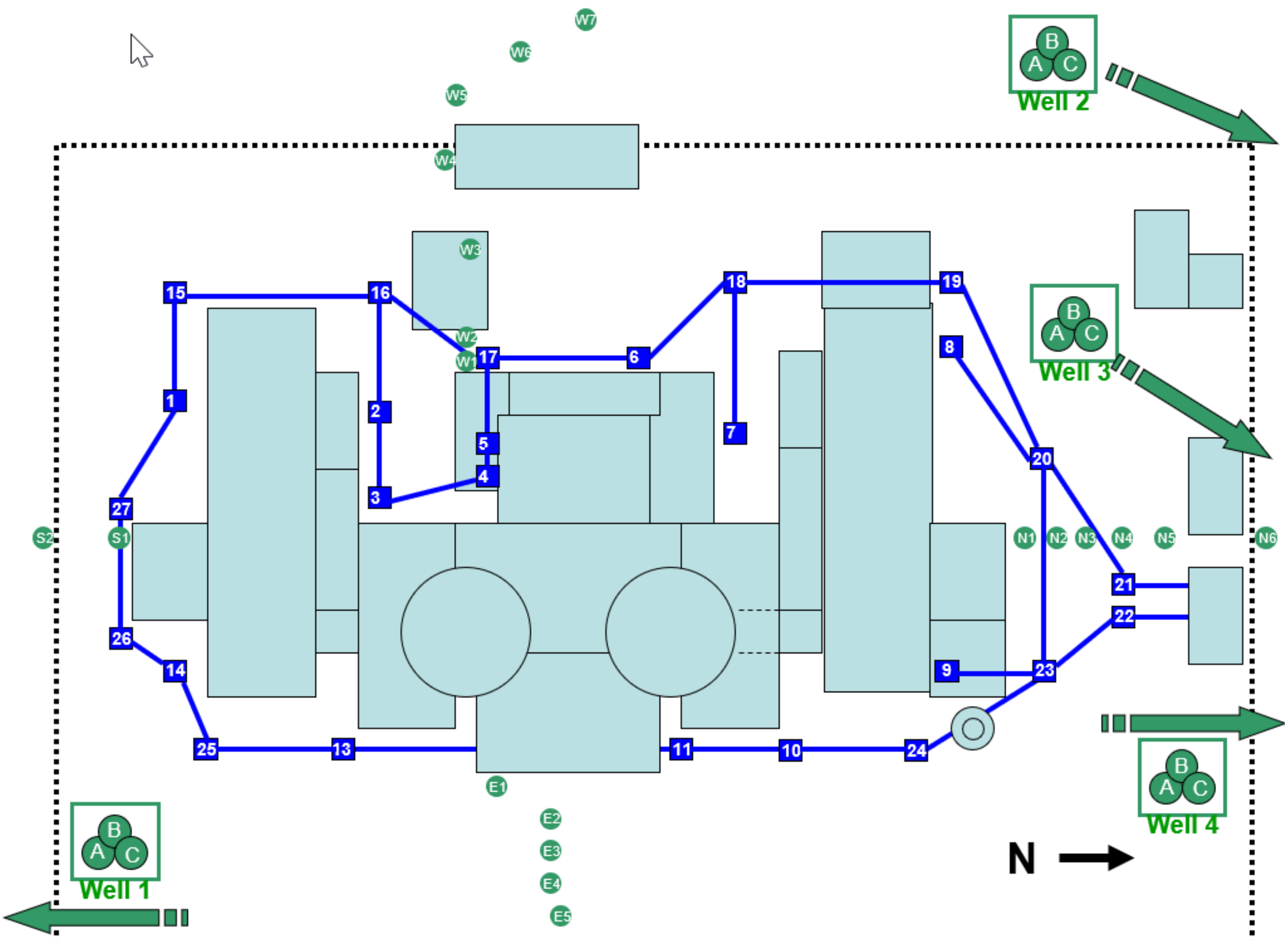

Figure 5, Underdrain System and Groundwater Monitoring Wells

Table 13: Summary of Onsite Groundwater and Outdoor Piezometer Samples

Sample Type	Functional Location	Spring H-3, pCi/L	Fall H-3, pCi/L
Outdoor Piezometer	N-3-83	260	336
Outdoor Piezometer	E-2-83	264	252
Outdoor Piezometer	S-2-89	<158	<163
Outdoor Piezometer	W-7-83	<158	<163
Monitoring Well	1A	<158	<163
Monitoring Well	1B	<158	<163
Monitoring Well	1C	<158	<163
Monitoring Well	2A	<158	<163
Monitoring Well	2B	<158	<163
Monitoring Well	2C	NS	NS
Monitoring Well	3A	<158	268
Monitoring Well	3B	<158	<163
Monitoring Well	3C	NS	NS
Monitoring Well	4A	<158	<163
Monitoring Well	4B	<158	<163
Monitoring Well	4C	<158	<163

(<) Less than values represent the MDA of the instrument at the time of analysis

NS- Insufficient sample volume for analysis

The Underdrain manholes are sampled and analyzed quarterly for principal gamma emitters and tritium by PNPP personnel in accordance with site procedures. The tritium results of samples obtained in 2021 can be found in Table 14.

On December 16th, 2021 tritium was detected in Underdrain Manhole 20 during quarterly sampling. The tritium concentration was 1750 pCi/L with no detectable gamma activity. A backup sample was obtained on December 17th, 2021 confirming there was detectable tritium activity present. The tritium value was 2050 pCi/L which exceeded voluntary reporting requirements, of 2000 pCi/L, to local agencies as specified in plant procedures. A voluntary report was made on December 17th. An investigation, chemistry sampling plan and tritium action plan were implemented to identify the source of the tritium. Actions are still being performed and monitoring will continue in accordance with plant procedures. Tritium activity has returned to background levels since discovered in December.

Effluent tritium activity LLDs are classified as μCi/ml in the ODCM. Groundwater reporting levels for tritium activity are stated in pCi/L. The unit conversion from μCi/ml to pCi/L causes a change of nine orders of magnitude. Underdrain manhole 20 and 23 effluents pathway is Emergency Service Water. In 2021 there was no tritium activity detected in Emergency Service Water.

Table 14: Summary of Underdrain Manhole Samples

Underdrain Manhole	Quarter 1 H-3, μCi/ml	Quarter 2 H-3, μCi/ml	Quarter 3 H-3, μCi/ml	Quarter 4 H-3, μCi/ml
20	<1.0E-05	<1.0E-05	<1.0E-05	1.24E-06
23	<1.0E-05	<1.0E-05	<1.0E-05	<1.0E-05

(<) Less than values represent the ODCM LLD value

12.1 Voluntary Notification

During 2021, Perry Nuclear Power Plant did make a voluntary NEI 07-07 notification to State/Local officials, NRC, and to other stakeholders required by site procedures. Underdrain Manhole (UDM) 20 is sampled quarterly as discussed above.

On December 16, 2021 UDM 20 tritium activity was detected at a concentration of 1750 pCi/L with no detectable gamma activity. Notifications to the site were performed and on December 17th a back-up sample confirmed elevated tritium levels of 2050 pCi/L. This concentration is above the 2000 pCi/L value for voluntary notifications. The Event of Potential Public Interest (EPPI) for the detectable tritium above the voluntary notification level was completed at 17:24 on December 17, 2021 by PNPP's Regulatory Compliance Section. Tritium levels remain below the EPA drinking water limit of 20,000 pCi/L. Underdrain Manhole 20 is on the north side of the plant as shown in Figure 5. Perry has an underdrain system to prevent groundwater hydrostatic pressure buildup on plant structures. The underdrain system has two installed gamma radiation monitors that assess the process stream prior to the stream flowing into the Emergency Service Water system. No known leak or spill was identified. Walkdowns and additional sampling are being performed from the Underdrain System, plant piezometer tubes, and the site to identify the source of the tritium. Tritium activity continues to be monitored in accordance with plant procedures.

13.0 Abnormal Releases

There were no abnormal gaseous releases in 2021. PNPP had two abnormal liquid release pathways present in 2021 as discussed below.

13.1 Nuclear Closed Cooling

Residual radioactivity remains in the Nuclear Closed Cooling (NCC) system due to past leakage from the reactor coolant system. This radioactivity will continue to be monitored, and any detectable activity measured from the NCC system to Emergency Service Water is tracked and recorded as a continuous abnormal release. NCC had no alpha, tritium, or gamma activity from January 2021 to November 2021.

On December 14, 2021 the Nuclear Closed Cooling Process Radiation Monitor count rate increased indicating a radioactive leak into the system. After an investigation and chemistry sampling it was determined that the Reactor Water Clean Up (RWCU) A pump was the cause of the in-leakage. A failed thermal neck on the RWCU A pump was the activity source. The RWCU A pump was taken out of service to stop the radioactive ingress to NCC. The NCC gamma isotopic activity in the system was removed by decay of short-lived nuclides and using the side-stream demineralizer to remove the long-lived isotopes. The thermal neck was replaced and RWCU A pump was returned to service.

As a result, the NCC system in December (Quarter 4) contained tritium activity and was recorded as a continuous abnormal release. Tritium was the only isotope identified in the NCC monthly composites with 3.27E-04 Ci released. Activity was assessed in the monthly effluent surveillance, and exposure is accounted for in Table 2, Table 2a, Table 3, Table 7, Table 8, Table 9, Table 10, and Table 12.

NCC Continuous Release	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Total time period for continuous release, min	0.00E+00	0.00E+00	0.00E+00	5.04E+04
Total volume released, liters	0.00E+00	0.00E+00	0.00E+00	3.77E+04
Average SW quarterly flow rate, L/min	1.55E+05	1.34E+05	1.69E+05	1.30E+05

NCC Total Activity	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Annual**
A. Fission and Activation Products (Ci)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B. Tritium (Ci)	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]	3.27E-04	3.27E-04
C. Noble Gases (Ci)	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]
D. Gross Alpha (Ci)	<1.0E-07 [1]	<1.0E-07 [1]	<1.0E-07 [1]	<1.0E-07 [1]	<1.0E-07 [1]

13.2 Auxiliary Boiler

In March of 2020 tritium activity was detected in manhole 23's first quarterly sample. The source of this activity was auxiliary steam leaks bleeding into the auxiliary boiler deaerator. This excess water was drained into the underdrain system. Once the intrusion was discovered the draining was stopped. Manhole 23 was monitored, and tritium levels returned to <LLD. No activity was detected in the effluent pathway of Emergency Service Water. The auxiliary boilers had been secured and drained in 2019 before tritium was introduced into the deaerator. Auxiliary steam valves were investigated and repaired. The auxiliary boiler deaerator was filled and drained multiple times. Tritium sampling and analysis of the deaerator still showed tritium in-leakage. The auxiliary boiler deaerator tritium source was not discovered and investigation continues.

Sampling and analysis protocols for abnormal Auxiliary Boiler releases were added to site procedures to quantify the tritium releases using an ODCM-compliant methodology when the boiler was vented to atmosphere.

Activity was discovered in March, April, June and November of 2021 (Quarters 1,2 and 4). The boiler was sampled and analyzed for tritium and gamma emitters each time it was operated. Samples were composited and analyzed as a batch release using the ODCM. Tritium was the only activity found in the auxiliary boilers. This activity was assessed in the monthly effluent surveillance, and exposure is accounted for in Table 2, Table 2a, Table 3, Table 7, Table 8, Table 9, Table 10, and Table 12.

Auxiliary Boiler Batch Release	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Total time period for batch release, min	1.09E+03	7.18E+02	0.00E+00	2.59E+02
Total volume released, liters	2.70E+04	1.78E+04	0.00E+00	6.41E+03
Average quarterly flow rate, L/min	2.48E+01	2.48E+01	0.00E+00	2.48E+01

Auxiliary Boiler Total Activity	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Annual**
A. Fission and Activation Products (Ci)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B. Tritium (Ci)	8.53E-03	9.19E-04	<1.0E-05 [1]	1.57E-02	2.52E-02
C. Noble Gases (Ci)	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]	<1.0E-05 [1]
D. Gross Alpha (Ci)	<1.0E-07 [1]	<1.0E-07 [1]	<1.0E-07 [1]	<1.0E-07 [1]	<1.0E-07 [1]

1 – (<) Less than the ODCM-required lower limit of detection, units in µCi/mL

14.0 Bibliography

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