

Detection and Release of Tritium at Perry Nuclear Power Plant

Cecil Roll, Julio R.
Students, Columbus, Ohio

ABSTRACT

This paper provides an in-depth examination of tritium behavior, release, and detection in the Perry Nuclear Power Plant, a GE BWR-6 reactor located in Perry, Ohio just 40 miles northeast of Cleveland, Ohio. Tritium, a radioactive isotope of hydrogen, is produced in boiling water reactors primarily through reactions involving Lithium-6 and as a product of ternary fission from Uranium-235.

The report presents detailed quarterly data from 2023 on both liquid and gaseous tritium effluent releases, as well as other radioactive effluents, including Cobalt-60, Iron-55, and Carbon-14 all based on data from the NRC. Our analysis of the data shows that gaseous releases were significantly higher than liquid releases, due in part to differences in the way both are contained and their decay properties.

The detection methods for tritium are discussed, with liquid scintillation counters used for aqueous samples and ionization chambers employed to monitor gaseous effluents. The paper also introduces the theoretical fusion fuel cycle involving tritium and deuterium, emphasizing the importance of tritium breeding via lithium blankets to sustain fusion reactions.

Further sections address technical questions raised during a related presentation, including the molecular form of gaseous tritium (T_2), the mechanisms of tritium production in reactors, and isotope separation techniques based on mass differences, such as gaseous diffusion and thermal chemical reactions.

Overall, this report aims to show the Tritium release from the Perry Nuclear Power Plant, and explain its detection; separation; and release from the coolant and the plant.

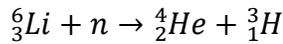
INTRODUCTION

The Perry Nuclear Plant is a Boiling Water Reactor located near Lake Erie in the City of Perry, Ohio. The power plant, which Vistra Operation Company LLC currently

owns, is a GE BWR-6 with a Mark 3 containment structure. It outputs close to 1260 MWe and annually produces 10 GWh for the surrounding area.

Tritium is a radioactive isotope of Hydrogen that has 2 extra neutrons and is the basis behind what we are tracking in this report. In a BWR such as the Perry Reactor, it is usually produced by Lithium-6 reactions and is also created as a fission product. Tritium is notable because it decays through Beta-Minus decay. Releasing an Anti-Neutrino, Beta, and Helium 3. Tritium has a specific activity of 9,650 Ci per gram which is about $3.57E14$ Bq per gram [2]. While not normally dangerous to a person, it can increase one's chance of cancer if ingested.

Lithium-6 Reaction



Tritium Decay Reaction



RESULTS FOR PERRY'S TRITIUM RELEASE

Table I. Liquid Tritium Release [1]

Liquid Tritium Release	Total Released	Average Concentration
Quarter 1	0.664 Ci	2.79E-8 $\mu\text{Ci}/\text{mL}$
Quarter 2	0.553 Ci	2.43E-8 $\mu\text{Ci}/\text{mL}$
Quarter 3	0.164 Ci	5.64E-9 $\mu\text{Ci}/\text{mL}$
Quarter 4	0.0817 Ci	4.42E-9 $\mu\text{Ci}/\text{mL}$

Table II. Gaseous Tritium Release [1]

Gaseous Tritium Release	Total Released	Average Concentration
Quarter 1	1.70 Ci	0.291 $\mu\text{Ci}/\text{sec}$
Quarter 2	1.01 Ci	1.01 $\mu\text{Ci}/\text{sec}$
Quarter 3	1.84 Ci	0.231 $\mu\text{Ci}/\text{sec}$
Quarter 4	3.61 Ci	0.454 $\mu\text{Ci}/\text{sec}$

RESULTS FOR PERRY'S OTHER EFFLUENT RELEASE

Table III. Liquid Effluent Release [1]

Liquid Effluent Release	Total Released	Average Concentration
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Quarter 1	0.117 Ci	0.493 $\mu\text{Ci}/\text{mL}$
Quarter 2	0.00869 Ci	0.038 $\mu\text{Ci}/\text{mL}$
Quarter 3	0.00671 Ci	0.0231 $\mu\text{Ci}/\text{mL}$
Quarter 4	None Detected	None Detected

Table IV. Gaseous Effluent Release [1]

Gaseous Effluent Release	Total Released	Average Concentration
Quarter 1	3.47 Ci	0.254 $\mu\text{Ci}/\text{sec}$
Quarter 2	4.93 Ci	0.157 $\mu\text{Ci}/\text{sec}$
Quarter 3	5.47 Ci	0.136 $\mu\text{Ci}/\text{sec}$
Quarter 4	5.07 Ci	0.157 $\mu\text{Ci}/\text{sec}$

DISCUSSION ON THE RELEASE

Above, in Tables I through IV, different effluent releases are listed in detail, showing the total release measured in Curies and the average concentration of the release. All data for the releases was sourced directly from the NRC, detailing the radioactive effluent releases for Perry in 2023. This was measured in microcuries per milliliter for liquid releases, while gaseous releases were in microcuries per second. For the tables detailing other effluent releases, the data is summed from any fission, activation, and alpha products released.

Firstly, among both tritium and other effluent releases, gaseous release is much higher than liquid release. This can be explained by the fact that liquid effluents are much easier to contain, store, and process. As for gaseous effluents, they are still filtered to minimize the release, but many gaseous effluents have shorter half-lives, posing less of an issue. As for other effluents, based on research from the NRC, for liquid releases, Cobalt-60 and Iron-55 made up most of the effluent releases, with the contribution from alphas being marginal. For other gaseous effluent releases, Carbon-14 made up a large portion of the total release, with Iodine being marginal or not detected at all.

COMMON TRITIUM DETECTORS

There are 2 main phases we need to track for tritium. Starting with Liquid Tritium first, this is most easily detected through liquid scintillators. These work by turning the decay of Tritium into light which is then detected and measured by the scintillator counter. Most commonly using a solvent that when excited by energy from a radioisotope will emit light which then is detected by photomultiplier tubes. These tubes convert the light into electrical impulses that the counter can process to find the rate and energy of the decay. For Tritium, these liquid scintillators use the beta particle produced during decay as the means of detection. In reactors, they most commonly take a sample from a batch of liquid that needs to be tested, it is then separated for the

isotope being tested and is then placed into the scintillator's chemical cocktail.

The other phase and detection method is Gaseous Tritium. In this phase, Tritium is most commonly detected through an ionization chamber. These ionization chambers use ionizing radiation such as X-rays and Gamma rays to force gas molecules to become ionized. This causes the electrodes on both sides of the chamber to have current, which then can be read by an electrometer to find what kind of particles are in the gas. These are most used at the effluent vents or reactors to measure how much of specific isotopes are being vented.

FUSION CYCLE

The fusion cycle itself for tritium is, for the most part, theoretical, however, it can be simplified to a few simple steps. The first step of the cycle is to pump the reactor with gas that contains tritium and deuterium, removing any waste gas in the process, purifying the input. After purification, the next step is to separate any hydrogen isotope using methods like distillation or diffusion, described below. Next is the most important part of the cycle, tritium breeding, which sustains the cycle. This takes place after the fusion of deuterium and tritium, which gives off a neutron. This neutron is absorbed by a lithium blanket around the fusion core, which conducts the reaction above, producing tritium, continuing the fusion cycle.

QUESTIONS FROM PRESENTATION

One of the main questions we were asked from our presentation was "How can Tritium be gaseous". Well, while liquid Tritium isn't exactly special as to how it comes about, as it is its normal state, gaseous is a bit different. Through a bit more research we found that Tritium can form T_2 just like normal Hydrogen can form H_2 when at standard temperature and pressure. This gas is called Diatomic Tritium and is the backbone behind what our ionization chamber discussed above will detect.

Another of the questions we were asked was "What can produce Tritium in a BWR". While we talked on this a little earlier in the report. We didn't explain how fission can produce Tritium as a product. While Binary Fission is more common, Ternary Fission in Uranium-235 will produce 2 Neutrons and Tritium along with its other fission products. This happens at about a rate of 10,000 fissions for a singular Tritium atom. Along with this is the aforementioned Lithium-6 reaction that occurs when Lithium is used as an agent to stop Boric acid from corroding where the coolant goes.

Lastly, we were asked how one can separate Hydrogen isotopes in a reactor setting. Through more research, we found that it is mostly done through a form of weight separation. Specifically, since Hydrogen to Deuterium is a 2 times weight increase and Hydrogen to Tritium is a 3 times

weight increase it is comparatively easy to separate compared to isotopes such as Uranium-235 and Uranium-238. When in Gaseous form, one common method is by using diffusion. This is because when at the same temperature and energy, two isotopes will have different velocities. Allowing lighter or heavier isotopes to be separated off. When in liquid form, many methods are also available, with one common one being chemical. When a sample is heated to the point where a reaction would occur, lighter isotopes tend to react and evaporate before heavier isotopes. This method is often done for Heavy water production and is currently being studied to help separate Tritium more effectively.

CONCLUSION

This paper helps to summarize details of Tritium release and detection for a local plant, Perry Nuclear Power Plant. The details of effluent release were compiled and analyzed for both Tritium and other effluents, such as activation materials and alphas. Other key information on how to detect Tritium release was also detailed here, explaining how gaseous and liquid tritium releases are measured and detected. Next, a basic explanation of the tritium cycle in a fusion reactor was given, emphasizing how important Tritium breeding is to the fusion cycle. Other questions posed during the presentation of the material were answered as well, ensuring the reader can get a full grasp of the material outlined.

NOMENCLATURE

Li = Lithium
He = Helium
H = Hydrogen
T = Tritium
D = Deuterium
n = Neutron
 β = Beta
 $\bar{\nu}$ = anti-neutrino

REFERENCES

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