terraphase engineering

# Technical Memorandum

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| To: | Abby Thorne-Lyman, Director<br>Base Reuse and Economic Development<br>City of Alameda | From: | Andrew Romolo, PG<br>Terraphase Engineering Inc.<br><br>Carl Palladino, The Palladino Company, Inc. |
| cc: | | | |
| Date: | June 4, 2025 | Project No.: | 0284.001.013 |
| Subject: | **Pacific Fusion Evaluation** | | |

## Executive Summary

Terraphase Engineering and The Palladino Company completed an evaluation of the risks associated with the use of radiological materials at the proposed Pacific Fusion (PF) Demonstration System (DS) fusion power research facility. In general, although a developing technology, fusion power research facilities are relatively safe for local communities. Although the PF facility will use radioactive materials and generate radioactive waste, the risk to the Alameda community is low due to the following key factors:

1. The fusion process, radioactive materials (tritium), and radioactive waste will be heavily regulated by the State of California.
2. Tritium is a low health risk that is used and regulated in other research and development facilities, often as a tracer element. It is also used as a self-powered lights source that can be found in traffic signs, exit signs for emergency lighting and on watch dials.
3. The tritium fuel required by this proposed facility is highly valuable and difficult to procure thus incentivizing PF to control inventory while also meeting regulatory requirements to account for all the material.
3. The modeling results of worst-case release scenarios indicated public exposures fall well below regulated levels of exposure.
4. California regulatory agencies will put in place reporting requirements that will require radiological waste be properly handled, packaged, transported, and disposed of out of California.
5. Decommissioning (cleanup) is backed by financial sureties in accordance with state requirements and approval before radioactive materials are used.

6. A decommissioning plan will be required, implemented, and verified before release of the property for future reuse.

These factors suggest a low likelihood of radioactive materials being released into the Alameda community. In the unlikely event of a release, the potential impact on public health and safety would be minimal.

**Facility Site**

The proposed Pacific Fusion (PF) Demonstration System (DS) facility is a fusion power research facility located in Alameda, California. The facility would be constructed in an approximately 13 acres area bounded by Orion Street to the west, West Pacific Avenue to the north, Skyhawk Street to the east and West Ticonderoga Avenue to the south. The facility would be located in a light industrial area with the closest residential home approximately 886 feet directly east. Additional members of the public are located in the vicinity including more residential homes spanning from the north to the southeast and Encinal Junior and Senior High School to the southeast.

**Proposed Facility**

The proposed design of the fusion DS has not been finalized; however, it will feature a fusion device used only for research purposes and will not produce electricity for the power grid. The DS will use tritium (hydrogen-3), a radioactive material, as one of the fuels for the fusion reaction. Deuterium (hydrogen-2) is the other fuel for the reaction and is not radioactive or hazardous. When a fusion reaction occurs, the two materials combine to create helium and neutrons, plus thermal energy. A review of Frequently Asked Questions and Answers provided by PF on their website are generally accurate. However, the following should be noted:

- ***Is Fusion Safe?*** Their response states no long-lived radioactive waste is created, which depends on how you define "long-lived". Neutron activation (as discussed in this memorandum) can create materials to be radioactive for decades. The specific isotopes may not have a long half-life (as compared to many others), but the material will be radioactive thus requiring disposal likely as low level radioactive waste. A small amount of waste can be potentially produced as part of the facility operations. Additional waste will be generated when the facility is decommissioned.
- ***How will you assure that nothing is released into the community (storm drains, emission, etc)?*** They state that there are no pathways to releasing radiological materials, however that assumes the system works perfectly, it is truly closed loop, and there are no accidents. Accordingly, this memorandum discusses the potential impact on the community in an unlikely event of a release. The modeling results

indicate that public exposure would remain well below the established regulatory limits.

**Potential Operational Risks**

A review of the proposed operations of this facility indicate that the following are the primary risks to the surrounding community:

- Exposure to tritium, located in storage, processing areas, vacuum systems, and permeated materials.
- Exposure to neutrons generated from the fusion reaction that requires shielding and that create activation products.
- Exposure to particulate that contains tritium and/or activation products.

This memorandum has been prepared to evaluate these potential risks.

**Regulatory Framework and Radioactive Materials License**

The United States Nuclear Regulatory Commission (NRC) is currently developing regulations regarding the licensing of fusion energy systems. As an Agreement State, California must adhere to the minimum requirements of the NRC. The California Department of Public Health (CDPH) is the regulatory agency that will review PF's application for a Radioactive Materials License (RML). Although the CDPH is authorized and capable of issuing a RML for a fusion research facility, the state's specific regulations and requirements have not been finalized. In addition, PF 's application for a RML has not been finalized.

The RML application process is extensive and iterative and will require many interactions between the applicant (PF) and CDPH staff such that a final application meets all the necessary requirements for obtaining a license. CDPH has extensive experience reviewing and monitoring RMLs for tritium use in research laboratories and for devices that create and/or emit neutrons. Tritium is has been used in laboratory environments where it can be used as a tracer element. Commercial use of tritium often take advantage of it being a self powered light source where it has been used in traffic signs and emergency exit signs.

The RML requires extensive documentation including procedures involving public and worker safety, monitoring for tritium and neutrons, radioactive material and waste inventory control, etc. The RML will require a Decommissioning Funding Plan (DFP) based on the quantity PF is planning to include on their RML (1400 to 1500 curies tritium). The DFP reduces the risk that radioactive materials and waste are abandoned without sufficient financial means to properly decommission the facility.

A key requirement for the approval of a RML is a visit by the CDPH to the proposed facility before possession and use of radioactive materials commences. This requirement ensures that PF has met all the conditions of the RML and it is prepared to implement the requirements. In addition, likely within the first six months of operations, the CDPH will conduct a formal inspection to verify PF's operations are meeting the licensing requirements. After the initial inspection, annual inspections will likely occur as continued verification. Any violations must be properly corrected within a required timeline. Egregious violations can lead to a cease and desist order and eventual termination of the RML. These regulations and policies reduce the risk that PF will not meet the RML requirements.

**Radiation Monitoring**

The CDPH will require specialized monitoring systems for tritium and neutrons to prevent not only worker exposure but also public exposure. These systems are maintained and implemented by qualified and trained professional staff including a Radiation Safety Officer (RSO). The RSO is named on the RML, and can only be replaced upon CDPH approval, is ultimately responsible for maintaining compliance with the requirements. Although the specific monitoring program had not been completed at the time of this evaluation, the final plan is required for the RML and CDPH will review it to verify that it is sufficient for the protection of the public.

**Hazardous Materials Use**

Tritium is a potential hazard to the public, workers and environment if not properly controlled and monitored. Deuterium is not a hazard and is found in small quantities in nature, predominately in water. Helium is an inert gas and not a hazard to the public or environment if released into the atmosphere. Neutrons are a potential hazard to the public, workers and environment if not properly controlled and monitored.

Chemicals used at the facility could range from cleaning solvents to lubricants to paints and epoxies. Specifically, large quantities of a dielectric oil, Mivolt DF7, which is a Class IIIB combustible (flash point above 200 degrees Fahrenheit), with a flash point of 381 degrees Fahrenheit, is used in the device for cooling electrical system. The oil is unlikely to pose a significant hazard to the public or environment if spilled as it is non-toxic and biodegradable. All hazardous materials must be included in a Hazardous Materials Business Plan submitted to the County of Alameda, which is a regulatory requirement.

**Tritium**

Tritium is a highly regulated substance that requires a RML from the CDPH to possess, store, use, handle and dispose of the material. The radioactivity of tritium is not considered

a significant hazard due to the very low energy of the beta radiation emitted when it undergoes decay. After radioactive decay, the tritium becomes helium, an inert gas. Monitoring in the environment requires specialized instrumentation or by collecting a sample (air, liquid, solid) for laboratory analysis.

Tritium is introduced in the upper atmosphere by natural processes thus is ubiquitous in nature at very low amounts. The radioactive half-life of tritium is 12.3 years, which means that half of the tritium atoms will undergo decay within that time. Tritium decays by emitting very low energy beta radiation (same as an electron) that are absorbed in air with 5 millimeters (0.2 inches), thus are not harmful to people unless the tritium is inhaled, digested, injected via an open wound, or absorbed into skin. However, since tritium is the element hydrogen, it can readily incorporate into a water molecule to form tritiated water or water vapor. Tritium can also diffuse into the surfaces of various materials, thus essentially contaminating parts of the DS device.

CDPH limits the quantity of tritium that PF may possess at any time at the facility; PF claims that amount is expected to be 1,500 curies. The tritium will be stored as a solid or gas and approximately 100 curies is used for each experiment. Of that amount, three to ten percent of the tritium is consumed in the fusion reaction, the remaining amount is reportedly recovered in a closed loop system (details were not available at this time). Since tritium is a valuable material that is difficult to obtain, PF has an incentive to prevent a release to the environment. In addition, CDPH requires inventory control as a condition of the license and requires monitoring of tritium in the event of a release. Although the probability of a tritium release to the environment is low, conservative dose projections were modeled to provide a worst-case scenario for public exposure.

**Modeling of Public Tritium Exposure**

We conducted modeling to evaluate the worst-case exposure to the public in Alameda from a catastrophic release of tritium from the proposed PF facility based on conservative assumptions. The model assumed that 100 percent of the possession limit allowed (1,500 curies) would be released from the facility and would be transported to the east at an average wind speed to the nearest resident. The dose to the resident was estimated at 0.5 millirem which is only five percent of the United States Environmental Protection Agency's (EPA) emission limit of 10 millirem.

The model was rerun to increase the amount of tritium released from the facility to 2,500 curies. That amount is our estimate of the maximum amount that PF would use during their experiments. The dose to the nearest resident increased to 0.8 millirem or 8 percent of EPA's limit. Therefore, based on these conservative modeling results, we do not believe that a worst-case release of tritium would cause a health and safety concern for the public as defined by the EPA.

**Neutron Activation Products**

The production of neutrons from the fusion reaction is a risk due to neutron activation. Various materials can absorb neutrons thus causing becoming radioactive. These materials can remain radioactive for many years requiring proper management and eventually disposal as radioactive waste.

The preliminary design of the DS appears to feature a water shield that nearly surrounds the reaction chamber to prevent neutrons from traveling outside the facility that would expose the public. This feature is also important for worker safety. However, in a review of proposed facility designs provided by PF it is not clear if the final design will extend beneath the chamber. In such case, the concrete foundation supporting the water shield will be subject to neutron activation and may need to be managed as radioactive waste during decommissioning. Final design of the facility will confirm if the water shield extends completely around the chamber.

The proposed fusion reaction involves the implosion of a small metal cylinder that contains the tritium-deuterium target. Small radioactive particulates (containing tritium and/or activation products) will be formed and will need to be removed from the reaction chamber, stored properly and eventually disposed of as radioactive waste. The risk of a release is highly contingent on the procedure developed for this process. PF claims that after a test, surface contamination surveys will be performed to verify no residual contamination is present. In addition, parts of the fusion device may become radioactive, and those parts will also require proper management and disposal (specifics are unavailable at this time). The CPDH will also require monitoring and management of this waste stream, including during transportation and disposal out of the community.

**Disposal**

All radioactive waste will be shipped out of state for disposal to a licensed radioactive waste landfill according to PF. Disposal of any radioactive waste in California is challenging and the nature of the waste products from the DS will likely be prohibited. This eliminates the risk of disposal in the local community.

**Decommissioning and Termination**

The RML will require a DFP as previously discussed as financial surety that the facility will be cleaned up properly. When PF terminates the use of radioactive materials a decommissioning plan is submitted to the CDPH that includes proposed clean up levels. Upon acceptance, decommissioning efforts are completed then a final status survey is performed to document that any residual radioactive contamination has been removed

below the cleanup criteria. The CDPH reviews the final status survey report and if accepted, the RML is terminated. At that point the facility may be released for unrestricted use. This process is well documented and supported by many previous RML terminations, thus is a low risk to the community to inherit a contaminated property.

**Conclusions**

Through the CDPH's regulations and oversight, the Pacific Fusion DS facility will be highly regulated. Additional regulations for shipping hazardous materials, emergency plans, hazardous business plan, etc. that PF must adhere to will also reduce the risk to the community. PF is unlikely to allow the release of radioactive tritium, if only for worker and public safety but also to conserve a highly valuable and difficult material to procure. In the event of a catastrophic release of 1500 curies of tritium (the maximum amount allowed by CDPH) the highest exposure to a resident would be 0.5 millirem, well below any regulatory requirements. As added insurance, a DFP is required to ensure the facility will be properly cleaned up. We can continue to provide critical evaluation of the design, safety related procedures, assumptions, and RML as PF continues development of the facility.

**Limitations of Evaluation**

This evaluation is limited to the information provided by Pacific Fusion, the CDPH, NRC and currently available literature. Many of the details of the facility design, procedures, monitoring systems, etc. are in the development stage. In addition, a RML application has not been submitted or approved. Therefore, this evaluation can change as new information is provided and regulatory permits are finalized.

**Biographies**

**Mr. Romolo** is one of the founding partners of Terraphase and has 25 years of experience working as a geologist in the engineering and environmental consulting industry. He is a registered professional geologist in the State of California and has worked on projects throughout California, New York and New Jersey, including various brownfield redevelopment projects. He has extensive experience in the characterization and remediation of a wide range of contaminants, including technologically enhanced naturally occurring radioactive materials (TENORM). chlorinated solvents, petroleum products and metals.

**Mr. Carl Palladino** is a Principal Health Physicist with The Palladino Company, Inc. with over 25 years of radiological experience working with a wide range of federal, state and private clients including the U.S. Environmental Protection Agency, U.S. Department of Energy, Los Angeles County Radiation Management, and the California Emergency

Management Agency. He provides a wide range of environmental, radiological, training, compliance, and emergency management services. Mr. Palladino has diverse experiences as a responder to hazmat emergencies; managing hazardous/radioactive waste investigation/cleanup projects; consulting for emergency management projects including terrorism exercise design, implementation, and evaluation, as well as developing radiological response plans; and developing/conducting health and safety trainings.