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5 March 2021

AGL WHOLESALE GAS LIMITED

WORKS APPROVAL APPLICATION 1003907

RESPONSE TO SECTION 22(1) NOTICE TO SUPPLY FURTHER INFORMATION – QUESTIONS 8 AND 12

OPTIMISING FSRU OPERATIONS - CLOSED LOOP

8. Please provide information comparing the design of a closed loop only FSRU with the current proposal

The FSRU that has been chartered for use for the Project is designed to be able to operate in open, combined and closed loop mode. The main purpose of this is to allow the FSRU to switch to combined and then, closed loop operation during winter when the seawater temperature is low enough to present a risk of freezing sea water in the regasification heat exchanges. In combined and closed loop, steam produced by gas-fired boilers is used to heat the seawater. Combined and closed loop mode are less fuel-efficient operating modes generating significantly more air emissions and greenhouse gases when compared to open loop mode, as they require two or three gas-fired boilers to be in operation to generate steam.

Based on the temperature recordings undertaken in Western Port, it is not expected that the seawater temperature in Western Port would be low enough during the colder months to require closed loop operations. Combined loop operations may be required during the coldest periods.

As the FSRU that has been chartered for use for the Project is designed to be operable in open, combined and closed loop modes, the design of a 'closed loop only' FSRU would not differ from that presented in the Works Approval Application (**WAA**) and Environment Effects Statement (**EES**).

The WAA and EES documentation sets out the design and associated impacts from operating in open and closed loop regasification modes. A summary of the closed loop operations is set out below.

FSRU design for closed loop operation

Operation of the FSRU in closed loop mode involves the use of four reciprocating gas engines and either two or three gas-fired boilers as part of the regasification process. In comparison open loop would only require the use of four reciprocating gas engines. The FSRU will be fitted with either two or three MAC-90BF gas-fired boilers with a power rating of 60 MW steam heating capacity and maximum evaporation of 90 t/h. Two of the regasification boilers would be located on the lower deck with the third potentially located in a fully enclosed new deck house.

The boilers will only be required in either closed loop mode or combined loop mode to heat the LNG. The boilers will operate on boil-off gas and will also be fitted with economisers to enable the use of waste heat from the flue gases. Table 1 below outlines the design parameters for FSRU exhaust systems, including the gas-fired boilers required for closed loop operation. Refer to Section 10.3.6 of the Works Approval Application for further information.

Table 1 FSRU exhaust parameters

Parameter	Engine Exhaust 1	Engine Exhaust 2, 3 and 4	Boiler 1, 2 and 3
Make & model	Wärtsilä 6L50DF	Wärtsilä 8L50DF	MAC-90BF Boiler
Power rating	5850 kW	7800 kW	60 MW steam heating capacity
Rotational speed	514 RPM	514 RPM	-
Fuel type	Gas or Diesel	Gas or Diesel	Gas
Height above deck	35.9 m	35.9 m	35.9 m
Outlet orientation	Tilted 45° aftwards	Tilted 45° aftwards	Tilted 45° aftwards
Outlet location	Main funnel	Main funnel	Main funnel
Diffuser description	Silencer and economiser	Silencer and economiser	Economiser
Outlet area	0.90 m^2	1.00 m^2	1.70 m^2

RPM – revolutions per minute

FRSU operating parameters in closed loop

Operation of the FSRU in closed loop mode would involve a single intake of seawater (approximately 500 cubic metres) to fill the heat exchange piping. Once filled, the seawater intake and discharge ports would be isolated, and the seawater circulated within a closed loop. Seawater cooled in the heat exchanger is then reheated by steam from gas-fired boilers and continually circulated in the process, instead of being discharged from the FSRU as per the open loop mode.

Refer to Section 7.2.1.2 of the Works Approval Application and Section 4.3.1 of Chapter 4 *Project description* of the EES for further information on how closed loop regasification mode operates.

In addition to the single intake of seawater used for regasification, seawater is also required for cooling of the engines, auxiliary machines and the atmospheric dump condenser in closed loop mode. This seawater would be continuously discharged back into the marine environment following its use and is not used within a closed loop. This discharged seawater would be from 5°C to 12°C warmer than ambient seawater. Under closed loop regasification mode, seawater used for engine cooling would be discharged at the rear of the FSRU (see Table 2).

An atmospheric dump condenser would be required on the FSRU to remove the energy from any excess steam generated by the FSRU boilers. In normal operation, when in closed loop mode, there is no excess steam and water runs through the atmospheric dump condenser without any change in temperature. However, if there is an unforeseen operational upset that causes a regasification train to shutdown unexpectedly, then the atmospheric dump condenser is used to safely remove the energy of the excess steam until the system is fully shutdown. The atmospheric dump condenser would also be used to remove the heat from burning any excess boil-off gas in the regasification boiler if the minimum send out (**MSO**) compressor cannot be used due to maintenance or any unexpected outage.

Table 2 shows the various discharges associated with continuous operation in closed loop and the relevant discharge port locations on the FSRU. In closed loop operation, there would be a discharge from the various cooling systems, atmospheric dump condenser and the freshwater generator. There is a main generator freshwater cooler on each side of the vessel. At peak production in closed loop, the discharge would total 187,000 m3/d (excluding the intermittent flows for ballast water, water curtain and fire water testing).

Refer to Section 12.2.4 of the Works Approval Application for further information on FSRU discharge design characteristics.

Table 2 Continuous closed loop discharges

Closed loop discharges	Flow rate (m^3/d)	Temperature (°C)	Discharge location
Main Generator FW Cooler	58,600	+12	Duty - discharge to rear
Auxiliary FW Cooler	45,800	+5	Discharge to rear starboard
Atmospheric Dump Condenser	80,400	0	Discharge to rear port side
Freshwater Generator	2,100	+8	Discharge at rear of FSRU. Note, flowrate has been rounded.
Total for closed loop	**187,000**		

BEST PRACTICE

12. Clarify how the near-field model tested a range of outfall configurations to demonstrate how outlet port number, spacing and configuration were tested.

The near-field modelling tested a range of outfall configurations for the FSRU as described in CEE Report *"Plume Modelling of Discharge from LNG Facility"* dated August 2018 (**2018 Plume Report**), and filed with the IAC Panel in Technical Note 007 (IAC Document Number 135).

The 2018 Plume Report examined the near-field dilution of the discharge of cooler seawater from the FSRU. Various options to discharge the cooler seawater were assessed. This information was prepared as an input to assessments evaluating the ecological effects of the Project within the marine environment, to be used in support of:

- A referral under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act),
- A referral under the Victorian *Environment Effects Act 1978*, and
- Requirements under the Victorian *Flora and Fauna Guarantee Act 1988*.

Near-field Model was INITDIL

The CEE model INITDIL was used for near-field modelling. The model has been published in peer-reviewed publications and the predictions have been verified by matching the predictions with field measurements at various outfalls overseas and in Australia (Devonport, Hobart, Strahan, Latrobe Valley, Bunbury).[1] The results were checked by confirming that very similar dilutions are predicted using other models such as Cederwall and VPLUME.

The assessment concluded that the discharged seawater would dilute rapidly after discharge, with the initial dilution at the seabed depending on the number and depth of discharge ports and the velocity of discharge. AGL's preferred design is a six-port discharge. Fewer discharge ports have been considered in this investigation for comparison purposes only.

The near-field modelling investigated various options to achieve a high initial dilution. The results of the near-field modelling showed that with discharge from six high-velocity ports, (which for the purposes of the model run were situated on the east side of the FSRU), the discharged plume will achieve a high dilution and produce a diluted field near the seabed that would be 0.35°C cooler than ambient seawater (dilution of 20:1). This field will mix further with tidal currents.

[1] See, for example, IG Wallis *(1991) "Verification of Ocean Outfall Performance Predictions", Proc. ASCE, J. Env. Eng. Div., _107_, EE2, 421-425; CEE (2010) "Blackmans Bay Effluent Dispersion and Water Quality Study" Report to Southern Water*

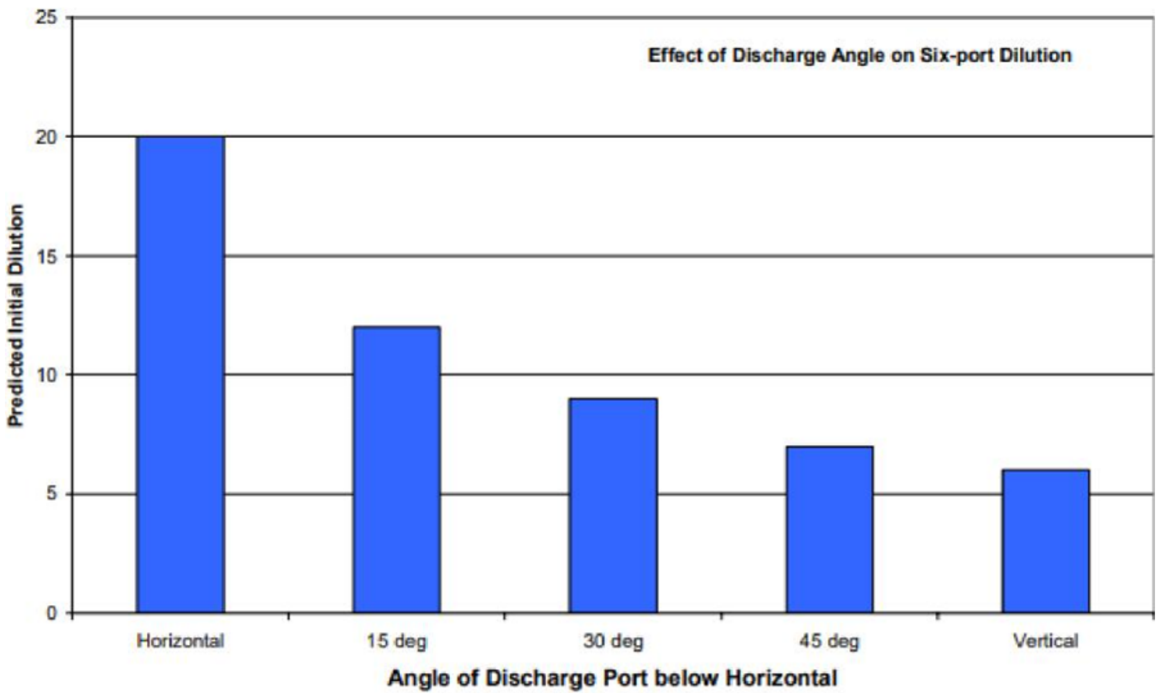
If an adjacent LNG vessel restricted the path of the plume, the dilution would be reduced. However, AGL has committed to operating the FSRU in a manner that is consistent with a minimised area of impact, being the modelled extent of the discharge plume as if the FSRU was operating *without* an adjacent LNG carrier.

At lower current speeds, the diluted field would form a stable layer on the seabed about 2 m thick. The layer formed at slack water will become mixed into the ambient seawater when currents increase above a threshold about 30 minutes into the subsequent tide cycle.

Examination of Angle of Discharge

Figure 3, extracted from the 2018 Plume Report, shows the predicted initial dilution for the case of discharge from six ports of 0.45 m diameter with a total discharge of 450,000 kL/d from a fully loaded vessel at low tide. With horizontal discharge, the dilution is predicted to be 20:1. For comparison, an alternative plume model published by Cederwall (1968) predicts a similar initial dilution of 21:1. VPLUMES also predicts a dilution of 20:1.

Figure 3. Effect of Discharge Angle on Initial Dilution



As can be seen in Figure 3, the dilution decreases from 20:1 with horizontal discharge to 12:1 at a discharge angle of 15 degrees and to 6:1 with discharge vertically downwards. The discharge decreases as the port angle declines below horizontal (tilted down) because the length of the plume between the port and the seabed shortens as the downward angle increases, resulting in less interfacial mixing and thus lower dilution. The conclusion drawn from these predictions is that the ports should discharge horizontally to maximise dilution.

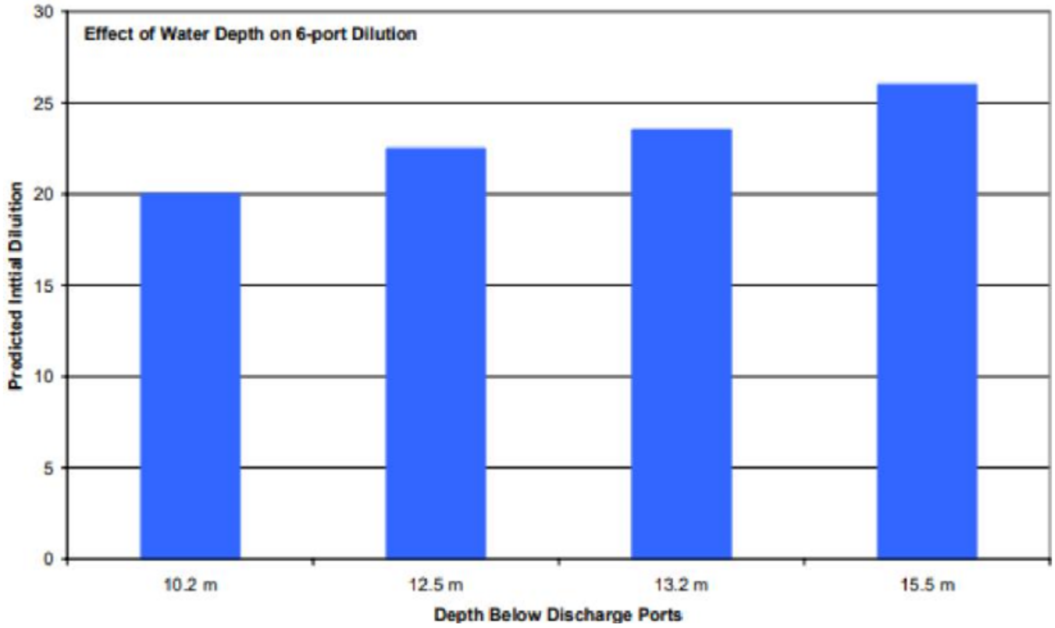
Examination of Water Depth

As the discharge would be seawater that is up to 7 deg C cooler than ambient, the discharge plumes will be slightly more dense than ambient seawater and sink slowly towards the seabed. Thus, the discharge ports must be located near the water surface to maximise initial dilution.

The FSRU will move up and down relative to the seabed due to (1) tidal water variation and (2) loading and unloading LNG and ballast water. Figure 4 shows the predicted initial dilution for these depth cases with a discharge of 450,000kL/d. At low tide and with a fully laden vessel, the initial dilution is 20:1, as shown in Figure 4 (corresponding to the dilution for the same case in Figure 3). This is the lowest dilution for the 6-port configuration. At high tide, or with a part or fully empty vessel, the depth below the water is greater and the predicted initial dilution also is greater.

Thus over a tide cycle, and during the period when the LNG vessel is being unloaded, the dilution will vary from 20:1 to 26:1. It is apparent that depth of water is a significant parameter, and consideration of the stage of the tide is required to assess the environmental effects of the proposed discharge.

Figure 4. Effect of Water Depth on Initial Dilution



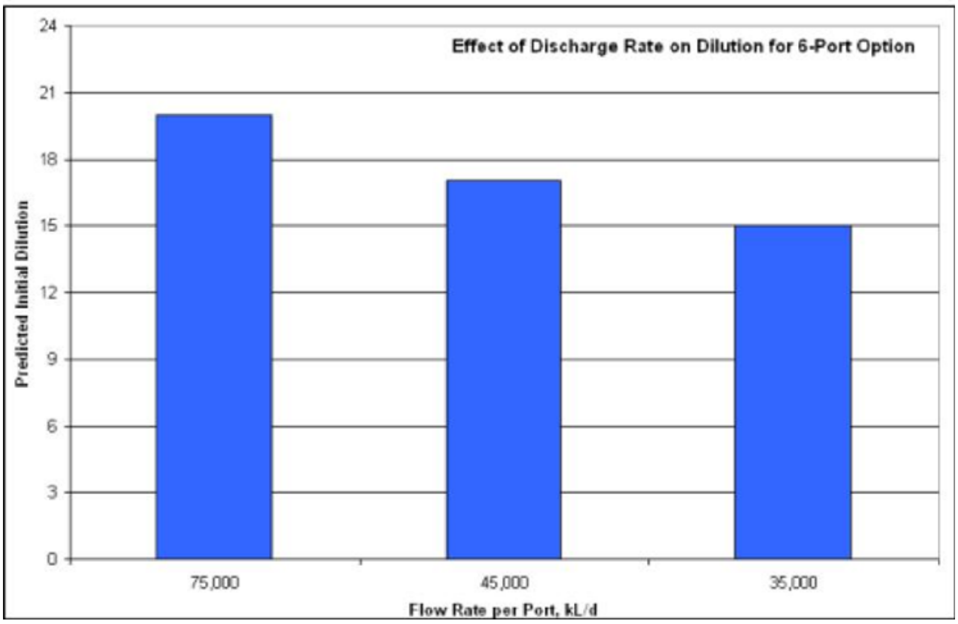
Examination of Discharge Rate

To establish the effect of discharge rate in the Crib Point situation, a series of runs were made for the 6-port case with three different discharge flow rates:

- 75,000 kL/d per port (full production of 450,000 kL/d via six ports);
- 50,000 kL/d per port; and
- 35,000 kL/d.

Figure 5 shows the predicted initial dilution for these discharge cases (assuming the diameter of the discharge ports remains fixed). Overall, the dilution decreases as the flow rate decreases, from a maximum of 20:1 at full flow (450,000 kL/d or 75 kL/d per port) to a minimum of 15:1 at 35,000 kL/d/port. The dilution would become even smaller at discharge rates below 35,000 kL/d/port.

Figure 5. Effect of Discharge Rate on Dilution for 6-port Option



It is apparent that the discharge from the three trains must be directed to specific discharge ports, to maintain the high velocity discharge required to achieve high dilution.

Examination of Number of Ports

The port options evaluated are:

- Single port of 1.1 m diameter on starboard side;
- Dual ports of 0.9 m diameter (one on each side);
- Four ports of 0.5 m diameter (two on each side); and
- Six ports of 0.45 m diameter (three on each side).

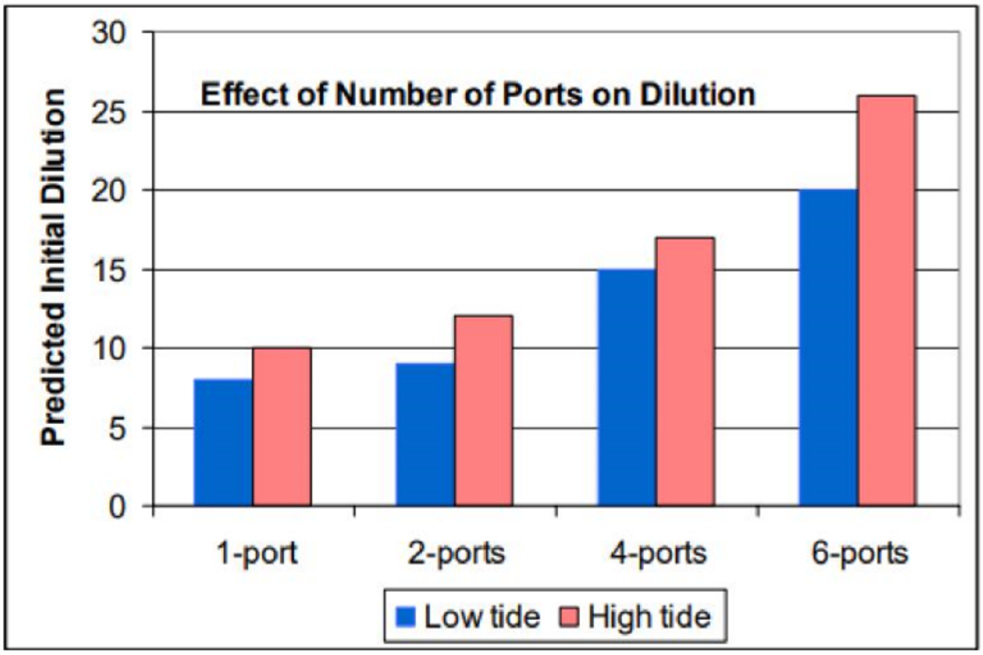
To examine the effect of the number of discharge ports on dilution, the minimum initial dilution for each of the four options has been calculated for the case of a fully loaded vessel at low tide with the maximum discharge rate of 450,000 kL/d.

As would be appreciated from the discussions of cases above, higher dilutions will be achieved when:

- It is high tide (compared to low tide);
- The vessel is nearly empty (as ports are higher above the seabed);
- The tidal velocity is higher than at slack water (see later discussion).

Figure 7 shows the predicted initial dilution for the four options concerning the number of ports. The single port option provides a dilution of 8:1 to 10:1 (from low tide to high tide); the 2-port option provides a dilution of 9:1 to 12:1, the 4-port option provides a dilution of 15:1 to 17:1; and the 6-port option provides a dilution of 20:1 to 26:1.

Figure 7. Effect of Number of Ports on Dilution – Constant Discharge



In terms of the temperature of the resulting diluted field on the seabed:

- A single port would produce a diluted cold-water field about 0.8°C cooler than ambient;
- A 2-port option would produce a diluted cold-water field about 0.7°C cooler than ambient;
- A 4-port option would produce a diluted cold-water field about 0.45°C cooler than ambient; and
- A 6-port option would produce a diluted cold-water field about 0.33°C cooler than ambient.

More ports produce a higher dilution, as would be expected. The proposed design adopts the highest level of dilution modelled and, accordingly, achieves the best environmental performance.

Summary of Findings from Near-field Modelling

The findings from the near-field modelling, which were applied in developing the project, are:

- A high velocity discharge (5 m/s) is required necessary to provide sufficient initial dilution.
- There should be six ports – two ports for each of the three trains on the FSRU.
- The ports should discharge horizontally.
- The ports should discharge well above the seabed, at about 2 m below the water surface.
- The initial dilution predicted by the near-field modelling is 20:1.