Design Specification: Targeted Flow Efficiency Heat Sink

Revision 1.0

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Revision History

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07/15/24	Rev 0.9	Mark MacDonald	First release
09/3/24	Rev 0.91	Mark MacDonald	Response to reviewers and format corrections
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1. Compliance with OCP Tenets

This contribution aligns closely with OCP tenets as detailed in this section.

1.1 Openness

Any vendor may take this contribution IP as is or to modify, customize, or optimize the described designs to suit a particular application. In particular, cold plate geometry and construction, fin spacing, fin thickness, pipe diameter, and slot width are key features which we anticipate will need to be altered to ensure a proper attach to the application's xPU size and power. Further, we anticipate that different vendors may propose changes to the described manufacturing methods in order to reduce cost or improve performance.

1.2 Efficiency

The Targeted Flow Efficiency Heat Sink has the word efficiency in its name for good reason. Use of this heat sink does require a compatible immersion tank infrastructure, but our measurements and analysis outlined in Section 2.2 below demonstrate that this technology can improve cooling capability by a factor of 2x or more without adding any additional power consumption to the immersion tank pumping systems.

1.3 Impact

The authors believe that Targeted Flow Cooling Technology will remove one of the key barriers to adoption of single-phase immersion cooling – limitations on the xPU TDP. We believe the availability of this technology will enable many more data center operators to be able to embrace the low PUE of single-phase immersion infrastructure for improved Total Cost of Ownership (TCO) and Environmental and Social Governance (ESG) advantages.

1.4 Scale

The Targeted Flow Efficiency Heat Sink is fully HVM-ready and should be compatible with any xPU design with appropriate modification.

1.5 Sustainability

The Targeted Flow Heat Sink is manufactured using materials and processes that are consistent with typical current heat sink designs and we do not anticipate any increase in environmental impact from the selection of the heat sink technology. In fact, as an enabler of highly efficient single-phase immersion technology, the net impact is expected to be energy saving and sustainability enhancing.

2. Overview

This section describes the Targeted Flow Heat Sink as well as the immersion tank requirements necessary to support its operation. Performance data will also be given. Key geometry features are identified. Opportunities for modifications and optimization, as well as suggested manufacturing approaches will be discussed. Geometry details for our exemplar prototype are given in Section 4.1.

2.1 Specification

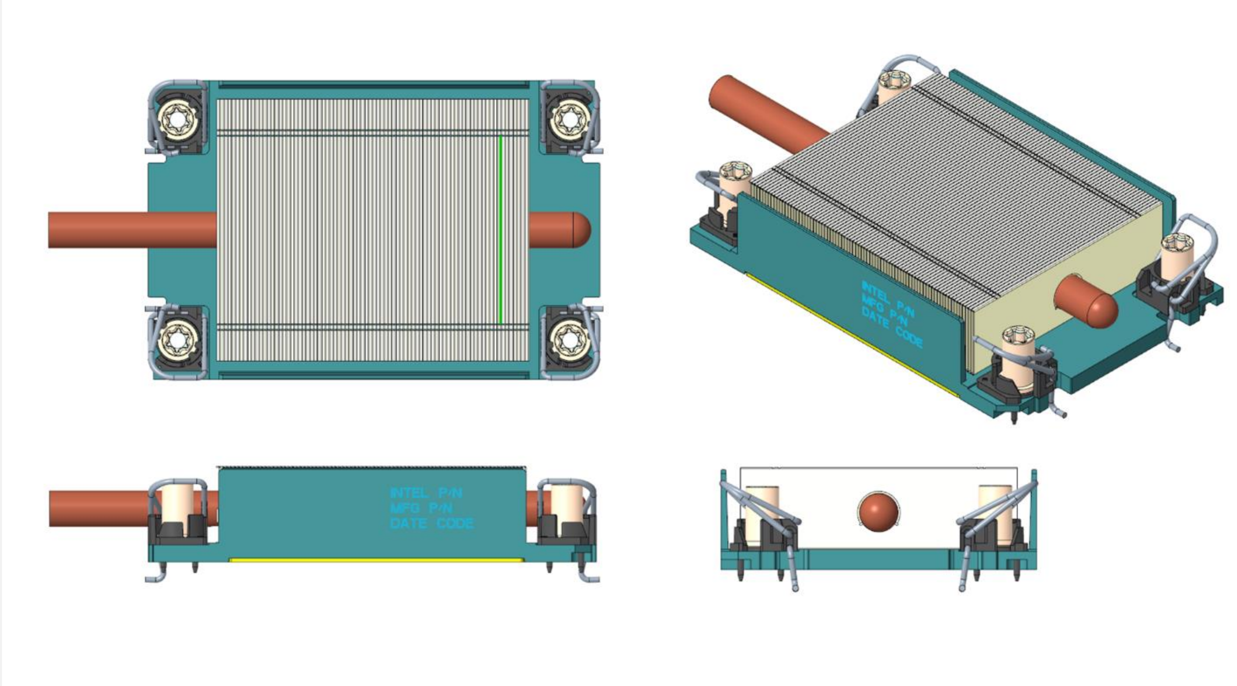


Figure 1 Overview of Targeted Flow Efficiency Heat Sink

The basic design for the Targeted Flow Efficiency Heat Sink is shown in Figure 1 and Figure 2. The design has several essential elements:

1) A baseplate similar to existing xPU heat sink designs, typically made of copper or copper alloy.

2) Mounting hardware (shown in Figure 1 as PEEK nuts used to mate to the motherboard/socket/loading mechanism).

3) A fin stack that is bonded to the baseplate. In this case the fin stack is a folded fin array stitched together running spanwise across the heatsink body.

4) A through-hole in the fin stack to allow for the penetration of the coolant delivery tube.

5) The coolant delivery tube that penetrates the fin stack. The coolant delivery tube has an axial slot in the side that faces the baseplate which injects coolant into the fin array during operation. The coolant delivery tube injection slot is visible in the exploded view of the heat sink shown in Figure 2 below.

6) The sidewalls integrated into the baseplate serve two purposes: first, they provide increased structural rigidity to the entire heat sink assembly; and second, the block warm coolant effluent from impinging on any memory DIMMs located adjacent to the xPU.

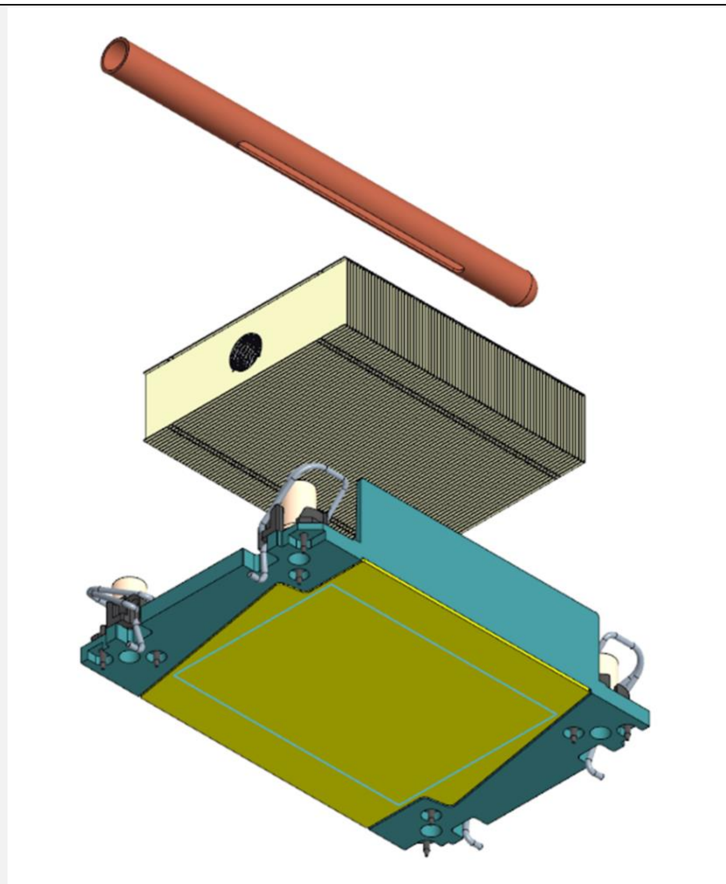


Figure 2 Exploded view showing coolant delivery tube with slot on baseplate-facing side

Once installed, the coolant delivery tube is connected so that a portion of the CDU return flow is directed to the heat sink. This arrangement is known as Targeted Flow Cooling. A schematic of the overall implementation is shown in Figure 3. Multiple tank vendors have or are developing single-phase immersion tanks that support this plumbing arrangement in various configurations. This OCP contribution is specifically and only referring to the heat sink design described herein and not to any particular overall implementation of Targeted Flow Cooling.

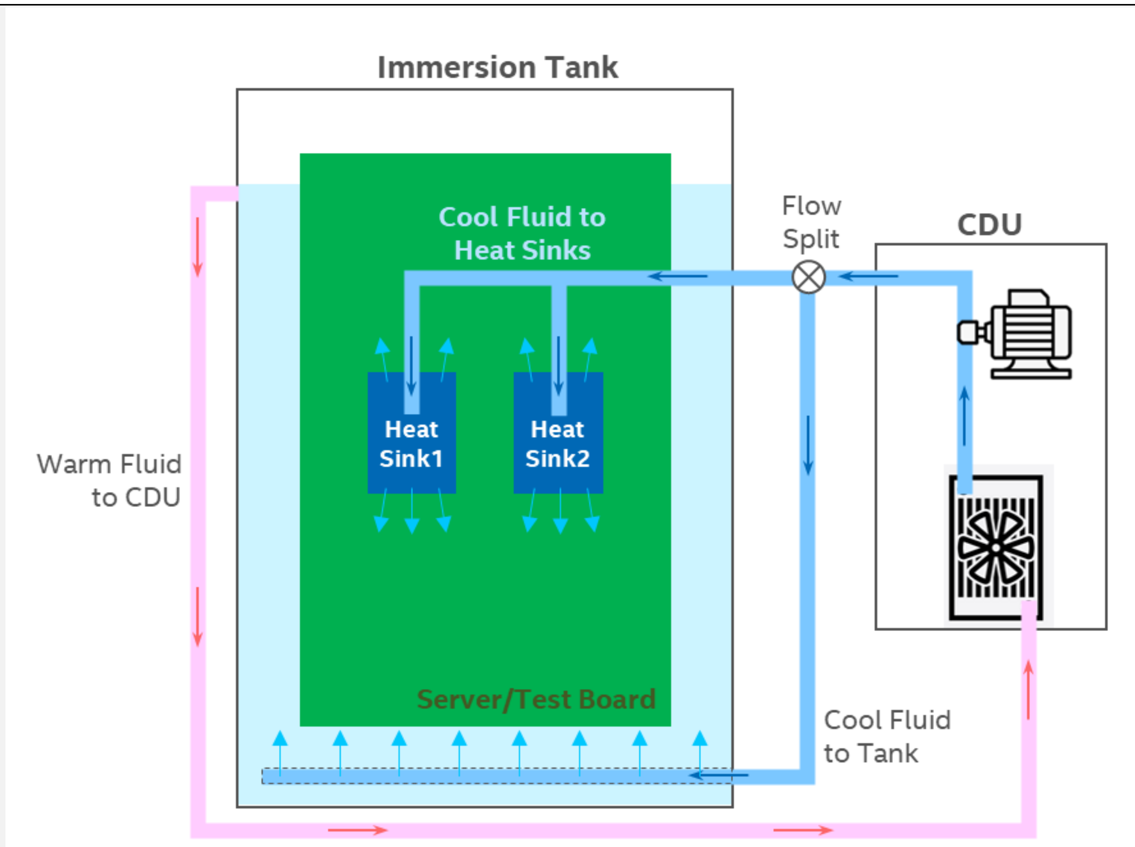


Figure 3 Schematic of Targeted Flow Cooling

2.2 Performance Data

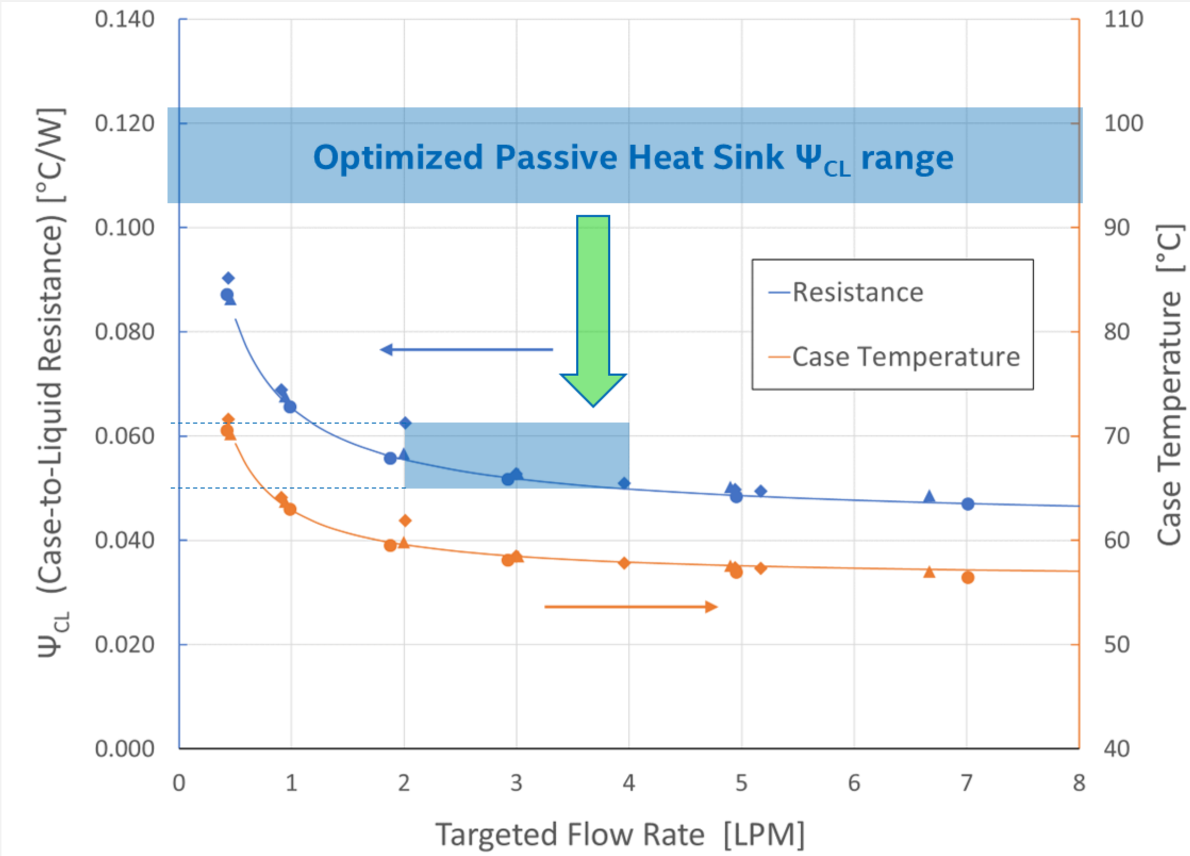


Figure 4 Representative performance data measured on an Intel Airport Cove TTV (4th Gen Xeon® CPU form factor) in PAO4

Representative performance data for the Targeted Flow Efficiency Heat Sink is given in Figure 4. This data was measured using an Intel Airport Cove TTV to emulate a Sapphire Rapids (4th generation Xeon® CPU). Testing was performed with PAO4 as the coolant and 6 mil Indium foil as the thermal interface material. The "optimized passive heat sink" range of Ψ_{CL} = 0.105-0.122 °C/W is shown for comparative purposes. This range was measured in the same configuration as the Targeted Flow Efficiency heat sink, but with a standard passive immersion heat sink that had been optimized for use in PAO fluids. Details on the optimization and geometry for the passive heat sink can be found in reference [1] by Saini, et al.

It is clear from Figure 4 that the performance gains associated with the use of the Targeted Flow Efficiency Heat Sink are significant. The overall case-to-liquid thermal resistance is lowered by a factor of 2 at the expected operating flow rate of 2-4 LPM for the heat sink. Based on a review of manufacturer specifications, current immersion tank CDU flow rates are on the order 8 LPM/ U, so the portion of the flow redirected from bulk recirculation to the Targeted Flow device is significant but not unreasonable.

The pressure drop for the Targeted Flow Efficiency Heat Sink is very low – less than 1 kPa for all flow rates shown in Figure 4. Accurate measurements are challenging because 1 kPa corresponds to a hydrostatic depth change of only 5 inches (12.5 cm) in PAO4 fluid, or roughly the height of the heat sink itself. Because this flow delivery occurs at the heat sink located in the middle of the fluid column, instead of the bottom of the tank where the bulk return is usually delivered, we expect in most cases the hydrostatic pressure advantage will outweigh any internal pressure losses for the Targeted Flow Efficiency Heat Sink and any changes in overall pumping power when using this configuration will be negligible.

2.3 Modification and Optimization

In addition to obvious modifications to the Specification which would be needed for any adaptation, such as adjusting the mounting nut locations to suit the application, there are a number of optimizations that are suggested for consideration:

1) Fin thickness, pitch, height, width, material, and assembly and manufacturing method (e.g., extruded vs. stacked fin vs. skived, etc.)

2) Baseplate thickness may be adjusted as appropriate within thermal spreading and structural rigidity requirements. Heat pipes, vapor chamber(s), or other high-performance spreaders may also be incorporated into the baseplate as needed to meet thermal requirements of the target application.

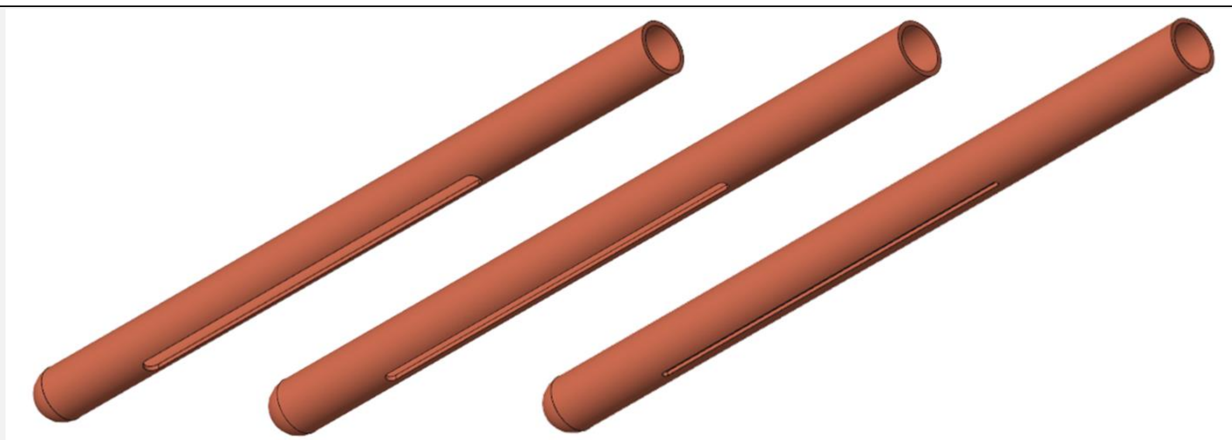


Figure 5 Optimization of coolant slot width (3 mm, 2 mm, and 1 mm examples shown)

3) Coolant delivery tube O.D., I.D., slot length, and slot width (illustrated in Figure 5). Adjusting slot width has a significant effect on the flow rate entering the fin stack.

4) Clearance between the side wall and the fin bank (shown in Figure 1)

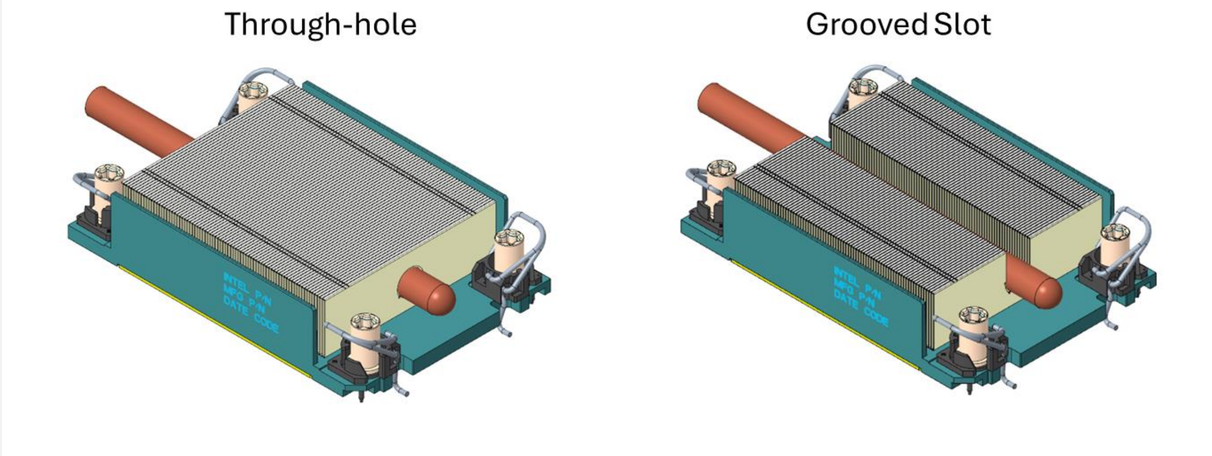


Figure 6 Coolant Tube mounting options: Through-hole vs. Grooved Slot

5) Manufacturing method for the coolant tube penetration style: the coolant tube can either be inserted via a through-hole in the fin stack or slotted into a grooved opening in the fin stack. These two approaches are illustrated in Figure 6. Thermally connecting the coolant tube to the fin stack is not important, but orientation of the slot opening should be maintained (facing the back-plate surface) via soldering, compression fitting, keying, or other method

2.4 Immersion Tank Plumbing Requirements

There are three primary requirements for the immersion tank set up for use with the Targeted Flow Efficiency Heat Sink:

1) The flow rate from the CDU must be sufficient to provide adequate flow (as defined by the application) to every Targeted Flow Cooling socket in the immersion rack. We expect this requirement to be easily met using existing pumps and designs.

2) The tank most provide a mechanism to split the CDU return flow into the Targeted Flow Cooling stream and the bulk return stream (see “Flow Split” label in Figure 3). This could be achieved through an active flow control system or a simple valve.

3) The tank must have a Targeted Flow Cooling distribution manifold to provide a fluid connection path from the Targeted Flow Cooling stream to each individual Targeted Flow Efficiency Heat Sink. Multiple tank vendors are currently preparing compatible tanks that should be available on the market in late 2024 or early 2025.

2.5 Miscellaneous Considerations

In addition to the features and optimizations described above, many of the normal considerations for heat sink design should be taken into account. These may vary by application, but are expected to include:

1) Adequate heat sink stiffness
2) Flatness of the mating surface.
3) Shock and vibration resiliency.
4) Leakage test may not be required (except for fittings and plumbing connections) since the Targeted Flow Efficiency Heat Sink effluent is designed to be vented into the immersion bath.

3. Environmental / Regulatory Requirements

Few regulatory requirements apply to heat sink design. Targets for storage and transportation conditions as well as shock and vibration requirements should be set appropriately to the application.

The Targeted Flow Efficiency Heat Sink is constructed from the same materials and using the same processes as most other heat sinks currently available in the ecosystem.

4. Physical Specifications

This section describes the specific dimensional details of the exemplar Targeted Flow Efficiency Heat Sink described in the Specification and that was used to measure the performance data shown in Figure 4.

4.1 Mechanical

This section only lists dimensions of key features of the exemplar design. Complete dimensioned mechanical drawings are also included in Appendix C.

4.1.1 Fin Stack

Fin pitch = 1.0 mm

Fin thickness = 0.3 mm

Fin height = 19.7 mm

Fin width = 68.4 mm

4.1.2 Coolant Deliver Tube

Tube O.D. = 9.5 mm

Tube I.D. = 7.9 mm

Slot width = 2 mm

4.1.3 Baseplate and Frame

Baseplate thickness = 5 mm

Gap from fin to structural side wall = 4 mm (nominal)

Overall X-Y = 115 mm x 78 mm

4.2 Rack Compatibility

The dimensions of our Specification will fit on a socketed Intel CPU in a 1U form factor rack. Other heights are possible with variation of baseplate thickness and fin height as described in Section 2.3.

5. Thermal Design Requirements

The design described in Section 2 and 4.1 was optimized for use in PAO4 or PAO6 fluid, but should be compatible with any other single-phase immersion fluid provided appropriate materials selections are used.

6. Interfaces

Customization of the mechanical interface to the board via an attach or loading mechanism will be required and will vary by application. Total interfacial loading, attach method, thermal interface materials, etc., are all expected to be similar to traditional heat sink design.

The connection from the Targeted Flow Cooling stream to each individual Targeted Flow Efficiency Heat Sink could be made with any appropriate fitting (UQD, barbed, swage, etc.), although we recommend a low impedance fitting since minor leakage would not create any performance issues.

7. References

1. Saini, S., McAfee, E., Carte, C., Damm, D., Sarangi, S., Gullbrand, J., and MacDonald, M., "Cooling Capability Enhancement in Single-Phase Immersion using Targeted Flow", **IEEE 2024 Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)**, 2024.

2. *Design Guidelines for Immersion Cooled IT Equipment*, OCP White Paper: https://www.opencompute.org/documents/design-guidelines-for-immersion-cooled-it-equipment-revision-1-01-pdf

Appendix A: Glossary

This glossary provides definitions within the context of immersion technology within data centers.

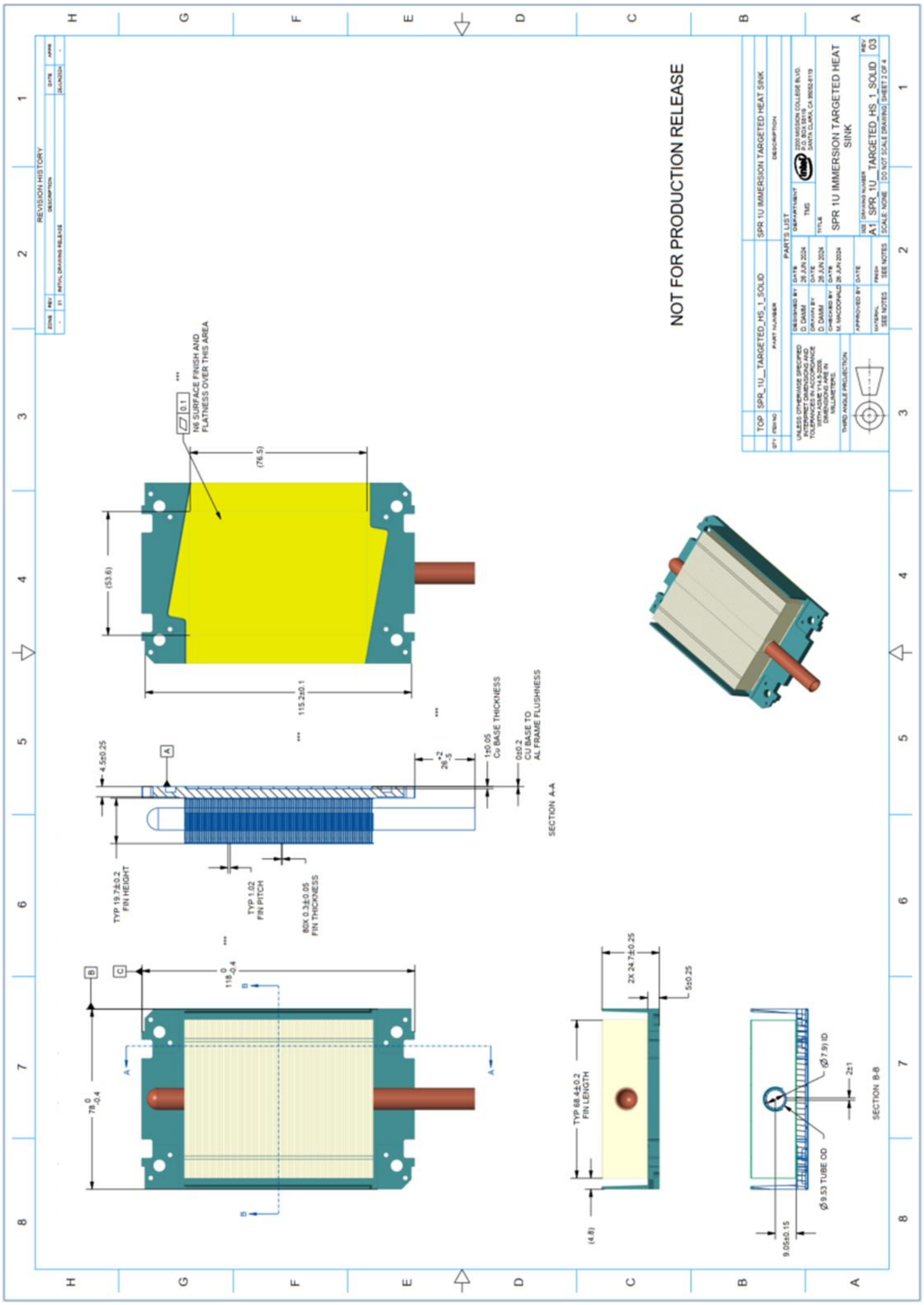
Coolant Distribution Units (CDUs)	A piece of equipment used in liquid cooling systems that is responsible for pumping and conditioning the coolant before it is distributed to the components being cooled.
Dual Inline Memory Module (DIMM)	A type of memory module that uses separate electrical contacts on both sides of the memory module to connect to a memory bus.
Environment, Social, and Governance (ESG)	A framework for evaluating the sustainability and ethical impact of an organisation's operations, focusing on environmental stewardship, social responsibility, and governance practices.
Polyether Ether Ketone (PEEK)	A high-performance polymer known for its excellent mechanical properties, thermal stability, and chemical resistance.
Polyalphaolefins (PAO)	Polyalphaolefins (PAOs) are synthetic hydrocarbons commonly used as base fluids in the formulation of lubricants. They are manufactured through the polymerization of alpha-olefin molecules.
PAO x (Polyalphaolefins)	A notation used to refer to specific variants of "Polyalphaolefins (PAO)", where "x" denotes the nominal fluid kinematic viscosity in "Centistokes (cSt)" at 100°C.
Power usage effectiveness (PUE)	A datacenter metric used to describe facility overhead power defined as the energy entering the facility divided by the energy used by the IT equipment.
Total cost of ownership (TCO)	Total Cost of Ownership (TCO) is a financial estimate designed to help consumers and enterprise managers assess direct and indirect costs related to the purchase of any capital investment, such as (but not limited to) IT hardware or equipment.
Thermal Test Vehicle (TTV)	A test device that simulates the form factor, thermal power, and heat distribution of an electronic component for testing purposes.
Universal Quick Disconnect (UQD)	A standardized connector that allows for the fast and secure disconnection and reconnection of fluid lines, commonly used in liquid cooling systems.
xPU	Any type of Processing Unit, including CPUs, GPUs, or specialized accelerators.

For the most up-to-date glossary definitions, please refer to the OCP CE Harmonized glossary.

Appendix B: References

- OCP Immersion Project: on-going project information (see wiki for details) https://www.opencompute.org/wiki/Cooling_Environments/Immersion
- OCP Immersion Project Community Call 03/19/2024 - https://drive.google.com/file/d/1zHW6AC6TE5xiM-49KQvUo8mhFKXmDSRb/view

Appendix C: Mechanical Drawings for Exemplar of Specification



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