Spotlight on Sustaining Member

When Is An ADR the Right Tool for the Job?

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Experimentalists seeking cryogenic platforms below 250 mK have essentially two choices: Dilution Refrigeration (DR) or Adiabatic Demagnetization Refrigeration (ADR) cryostats. There are particular applications where one or the other is the best tool. In some cases, either may be equally suitable. Let's discuss the differences.

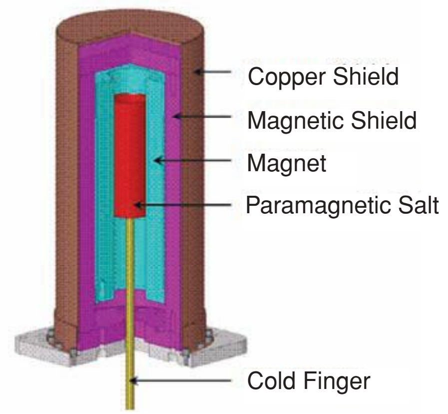
Because an ADR system is usually less expensive, requires less infrastructure, and is less complicated to operate than a DR, it can oftentimes be a more elegant choice for a host cryostat. In a laboratory already outfitted with one or more cryostats, the decision about the next cryostat investment may also hinge on considerations such as experimental throughput and cycle time.

But how does one go about effectively making the right choice? A review of a few principles may help make this decision process more straightforward.

Do I need a "continuous" or a "one-shot" system? The first requirement to establish is whether the system needs to be "continuous" or can be a "one-shot." DRs provide continuous cooling, where temperatures below 50 mK can be maintained for many weeks, months or even years. However, if an experiment's duration is on the order of hours or days, it may very well be that an ADR is a more appropriate experimental platform. ADRs, typically being one-shot systems, need to be recharged after the cooling energy is depleted.

Which system gives me the right amount of cooling energy? After figuring out whether you need a continuous system or not, then total cooling capacity must be considered. Although ADRs can be made in many sizes, a popular size that's commercially available provides cooling energy at the cold stage (usually referred to as 100 mK) of about 120 mJ. Since power is energy per unit of time (P=E/T), to determine the duration (Time) of cooling that's achievable (rearranging the equation: T=E/P) one simply needs to divide the total cooling capacity available (Energy) by the estimated parasitic heat load (Power). Let's assume that the total heat load from the wiring and the support system to the cold stage is one microwatt. Doing the math, we can calculate that the hold-time duration is 33 hours. Remembering that ADRs are one-shot systems, and using the one microwatt figure as a reference, we can easily conclude that halving the heat load will result in a doubling of the hold-time, and, similarly, doubling the heat load will halve the hold-time. For reference, typical background heat loads are typically lower than 150 nW.

Running with this thought, it's worth reviewing that the heat load at the cold stage is a function of the following five items: warm temp; cold temp; cable materials (conductor, insulation, and jacket); cross sectional area of cable materials; and length between the cold and warm temp locations. In addition to the heat conducted down all of the conductors, one needs to also remember to include heat dissipated in the experiment.



Section view of typical ADR, showing paragmagnetic salt pill in the bore of a superconducting magnet, surrounded by magnetic and thermal shielding.

An assessment of the required instrumentation wiring can fairly easily reveal whether an ADR can provide adequate cooling energy for the desired hold-time duration. If the ADR cannot achieve the required hold-time durations, a DR cryostat would likely be a wise selection.

Experimental throughput. Assuming that an ADR can provide sufficient cooling power and duration, another consideration is experimental turnaround time. Since ADRs are typically less massive (although this is not always true), and they require less time to cool to base temp after reaching 4K, ADRs usually allow for a higher throughput than do DRs. It should be noted though, that a top-loading DR (or ADR) can offer much shorter sample-to-sample cycle times than a system that must be warmed up in order to change the experimental setup.

Ease of temperature variation. Because the base temperature of an ADR is achieved by adjusting the current in the magnet power supply, changing the temperature is very straightforward. Using the PID control system, a user can easily sweep the temperature over a wide range while collecting data on the experiment. Temperature control of a DR can be difficult near the 3He/4He phase separation temperature (~800 mK). An ADR would have no such limitation.

Ballast mass cooldown. In addition to overcoming the parasitic heat load (conducted through the wiring and the support system), the ADR must also provide the cooling energy to cool the experimental payload from the "launch" temp (~3K when using a cryocooler) down to the base temperature. Performing this calculation is not a trivial task. One might be tempted to just calculate the heat to be removed from the payload as Q=m*k*dT, and then compare this to the 120mJ figure expressed earlier. But since the paramagnetic salt pill is providing cooling over the whole temperature range (from ~3K down to 100 mK), and due to the fact that the cooling energy of the salt pill is very much temperature dependent, the available cooling energy for initially cooling the payload to base temperature is several factors greater than the amount of cooling energy it can provide at 100 mK.

It should be noted that the ballast mass issue may not be as significant as it first appears. For instance, several kilograms of copper does not pose any problem for the size of ADRs discussed here.

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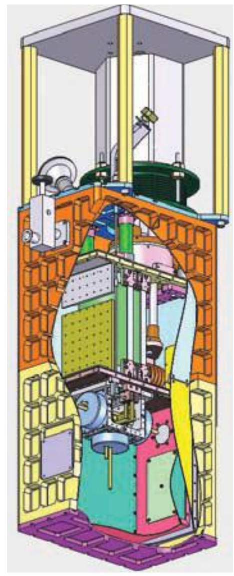
Should I worry about magnetic field sensitivity? ADRs employ a superconducting magnet, usually developing fields of 4T or higher. These systems generally employ passive shielding, which attenuate the stray field to be on the order of the strength of the earth's field. Additionally, the stray field associated with an ADR can vary slightly as a function of magnet current.

If this residual field strength is considered unacceptably high, supplemental magnetic shielding can be added to further attenuate the field. Since the residual field of an ADR is on the order of the earth's field, and since reducing the field to be smaller than the earth's field would require the supplemental shielding, an ADR is not appreciably less desirable than a DR in this regard.

System Complexity and Expense. As mentioned earlier, an ADR system is less complex than a DR system. Here are a few examples of the difference. An ADR is usually completely cryo-free, where even most "dry" DRs require LN_2 for their return trap.



Section view of HPD's Model 102 ADR cryostat. The Model 102 is one of family of commercially available ADR cryostats.

An ADR does not require a gas handling system (pump/compressor, manifold and valves, and pumping lines), nor does it require any Helium-3 gas, which has recently become scarce and expensive. ADRs are typically less costly than a comparable size DR cryostat.

Lab Makeup. Another consideration when deciding on a new instrument is the existing collection of cryostats in the lab. In some cases a lab will already have either a DR system or an ADR and what is important is that there exists a variety of experimental platforms. The ideal makeup of laboratory test systems will depend on the anticipated workload of the lab.

Examples of Ideal Solutions. If, for instance, your experimental setup includes a quantity of ten or more coaxial cables that terminate at 100 mK, and you want to stay at 100 mK for a few weeks, you will most certainly want to opt for a DR cryostat for your cold platform.

If your cryostat setup includes a couple dozen (or fewer) superconducting twisted pair wires, and your typical experimental duration is on the order of a day or two, an ADR is probably an excellent choice.

Choosing the right tool for the job. ADRs and DRs each have their own advantages and disadvantages. By understanding the experimental requirements, appreciating the differences in ADRs and DRs, and possibly doing some figuring, the user can successfully select the best system for the task at hand.