No lightweight matter

With stocks of helium-3 dwindling, **William Halperin** argues that unless we start conserving this vital resource, low-temperature physics could come to an end

What could be significant about a very rare isotope like helium-3? After all, it is the result of radioactive decay within the Earth and after millions of years it comprises only one trillionth of our atmosphere. Yet this element, which can also be produced as a by-product of the weapons industry, plays a vital role in fundamental scientific discovery, low-temperature physics, neutron detection and the fight against terrorism. The problem is that these sometimes conflicting interests have led to a crisis where demand for helium-3 far exceeds its supply. Indeed, shortages of this vital resource are causing physicists serious difficulties.

For many years, access to helium-3 was not an issue. After the Second World War, massive amounts of tritium were manufactured in nuclear reactors in the US and the Soviet Union as part of both nations' nuclear-weapons programmes. Tritium, a heavy isotope of hydrogen with a half-life of 12.3 years, naturally decays into helium-3, an electron and an antineutrino. Soon after the Cold War began, helium-3 became readily available for basic science.

Ironically, the current depletion of stocks held by the US government of this rare gas can be directly attributed to the expansion of the portal-screening programme in the US. This was initiated after 11 September 2001 to help prevent radioactive materials being smuggled across US borders and to protect against terrorist attacks. Helium-3 is useful in this context because it has a relatively high neutron-capture cross-section. Neutrons emitted by plutonium or highly enriched uranium therefore have a high chance of colliding with a helium-3 nucleus to produce a proton, tritium and 760 keV of energy. This nuclear reaction is also why helium-3 is the material of choice for detectors at neutron-scattering facilities around the world.

Dwindling stocks

The US currently produces about 8500 l of helium-3 from its current stocks of tritium each year (with likely an equivalent amount being produced in Russia). However, total current demand worldwide could be as high as 70 000 l per year. As a result of this growth in demand, the world's excess inventory of helium-3 in 2000, which had risen to 230 000 l of gas (held at standard temperature and pressure), has now shrunk essentially to zero. Concern over the lack of this resource and its threats to national security were voiced at a US congressional hearing in late April.

Oak Ridge National Laboratory

Something in the air Research at the Spallation Neutron Source could be hit by a shortage of helium-3.

Some heavy-water reactors in Canada produce tritium and it has been reported that 80 000 l of helium-3 have accumulated there over the years, although it appears to be inaccessible at present.

In the past half a century, low-temperature physicists have liquefied, solidified and studied helium-3, and have uncovered many of its unique physical properties. One serious impact of the helium-3 shortage has been to sales of cryogenic refrigerators. It has also affected low-temperature scientific programmes spanning a wide range of disciplines, including superconductivity, magnetism, mesoscopics, nanoscience, quantum fluids, quantum solids and quantum information technology. These programmes currently require about 4500 l per year and without access to helium-3 the refrigerator companies will cease operations and low-temperature science could come to an end.

Neutron detectors based on helium-3 have become essential at the dozen or so neutron-scattering centres around the world. The planned expansion of these facilities in the next decade will require amounts of helium-3 that are far in excess of any practical approach at conservation or recycling. For example, the Spallation Neutron Source at Oak Ridge in Tennessee will need about 100 000 l per year of helium-3.

Helium-3 neutron detectors are also widely used in the oil and gas industry to evaluate possible fuel-bearing geological strata. Here, a radioactive source leads the detector array in its progress down the bore hole and the resulting radioactive activation of the surrounding rock is detected with helium-3 neutron detectors. The information obtained is used to determine the porosity and hydrocarbon content of the rocks. Polarized helium-3 gas has also been developed as a valuable tool for magnetic resonance imaging (MRI) studies, where, for example, it can be passed through the lungs to provide much better image resolution than with conventional MRI.

Price hikes

For many years when stocks of helium-3 were running high, it cost less than $200 per litre. Now, however, it can cost anything from $500 (for US-government-approved scientific projects) to as high as $4000 per litre. Although researchers do not have to pay the highest prices, the main problem for scientific applications is that only a small amount of gas is available, irrespective of the price. the cost of producing helium-3 from a dedicated tritium factory would, in contrast, be about $12 000 per litre.

The US government's view is that this is unattractively high, so substantial efforts have been launched to find alternate neutron-detection technologies based on lithium-6 or boron-10 isotopes. Unfortunately, it may be quite a few years before such detectors are available, while companies want to deploy more helium detectors to capitalize on their research and development investment rather than develop new technologies. Worse still, there are no viable alternatives for low-temperature physics as cryogenic applications are specifically tied to the unique quantum-mechanical properties of helium-3.

Looking to the future, we will have to learn to recycle and conserve stocks. Scientific agencies in every country around the world will have to develop strategies to mitigate the shortage. Unwritten partnerships between industry and strategic interests, and between commercial providers of instrumentation and government, will have to be made explicit to encourage rapid development of new detectors. However, low-temperature science is in a special situation. A case must be made for a protected, continuing supply, even if it is at a lower level than now.

Correspondingly, refrigerator firms must redesign their instruments to be more efficient. A factor of two or three reduction in the requirements for a dilution refrigerator might be possible without compromising most applications. This would lessen the impact of the shortage in the near- and long-term. But unless there is renewed tritium production, none of us will, ultimately, have any helium-3, and this will be a major setback for science.

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