Molybdenum's nuclear mission

Nuclear power currently supplies some 11% of the world's energy needs. Without debating its pros and cons, everyone would agree that the spent fuel already in existence from more than 50 years of generation needs safe handling and disposal. Imparting greatly increased corrosion resistance to stainless steel, molybdenum is making a positive contribution to the ongoing safety of spent fuel management throughout the world.

Long-term dry storage

Nuclear fuel loses its efficiency after several years in a reactor and has to be replaced with fresh fuel. Most nuclear reactors in use today have a 'wet' discharge route. The spent fuel removed at refueling is placed in a purpose-built water-filled pool to dissipate heat and radiation, which continue to be generated. After the most intense heat and radiation has died away, the fuel can be removed for reprocessing or for long-term storage.

However, the lack of a permanent waste disposal strategy in the US and many other countries has meant that fuel has stayed in discharge pools for much longer than expected. The growing inventory of spent fuel in pond storage, heightened security concerns and the need to address earthquake and tsunami resilience after the Fukushima Daiichi disaster in 2011 has forced operators to find alternative storage solutions.

Dry cask storage is an increasingly popular option for nuclear plant operators, particularly in countries such as the US where there is no reprocessing route to deal with spent fuel. The US Nuclear Regulatory Commission (NRC) formally recognized onsite dry cask storage as safe for short to indefinite timeframes in the Continuing Storage of Spent Nuclear Fuel Rule, published in August 2014.

The difference with duplex

Most casks are constructed from high-performance stainless steel and concrete and designed to last for many years. In recognition of the trend towards *de facto* long-term dry storage, AREVA TN has developed a version of its NUHOMS® horizontal dry storage system incorporating molybdenum-bearing 2205 duplex stainless steel canisters. This stainless steel has been used to resolve concerns about canister aging and localized corrosion in marine environments.

The two-phase microstructure of duplex stainless steel is ideal for long-term nuclear fuel storage, and is especially suited to environments near the coastline due to the addition of 3% molybdenum. It provides superior strength (compared to austenitic stainless steel) and resistance to stress corrosion cracking, pitting and crevice corrosion, all common causes of deterioration in standard stainless steel grades in aggressive marine environments.

Duplex stainless steel is being actively marketed as an important enhancement to the long-term reliability of dry storage, forming a significant and redundant layer of protection when placed inside the thick-walled, steel-reinforced concrete storage modules.

Reprocessing and waste management

Apart from storage and ultimate disposal, the only other spent fuel management route available to nuclear plant operators is reprocessing. Here the mostly unburned uranium is chemically separated from the plutonium and fission products created while the fuel was in the reactor. In order to do this, the metal fuel casing is stripped away and has to be disposed of. This and certain other waste streams from reprocessing, such as contaminated equipment, are classified as intermediate level waste (ILW). ›

Duplex dry storage canisters being manufactured in North Carolina, U.S. © AREVA TN

Intermediate level waste drums at Sellafield made from Type 316L stainless steel. The drums are filled with waste and stored in stacks (one stack of ten drums under each white square with the yellow dot) in the Encapsulated Product Store at Sellafield, prior to final geological disposal. © Sellafield Ltd

Spent nuclear fuel has been reprocessed at the Sellafield nuclear site in Cumbria, UK, for more than fifty years, and much of the ILW from historic reprocessing was stored prior to a suitable waste treatment route becoming available. As the focus of the site shifted from commercial operation to remediation and hazard reduction in the 1990s, several waste management plants were constructed at Sellafield and began to deal with the stored ILW.

The final wasteform produced would need packaging in a material robust enough to provide adequate containment for further decades of on-site storage and ultimate geological disposal in accordance with UK policy. One of the biggest challenges to overcome in the safety case documentation approving the packaging was the risk of corrosion, not from the waste itself, but from chlorides in the atmosphere due to Sellafield's coastal location.

Stainless steel was considered to be the ideal material, with the addition of molybdenum to provide extra protection against chloride corrosion. Type 316L stainless steel typically containing 2.1% molybdenum was eventually selected.

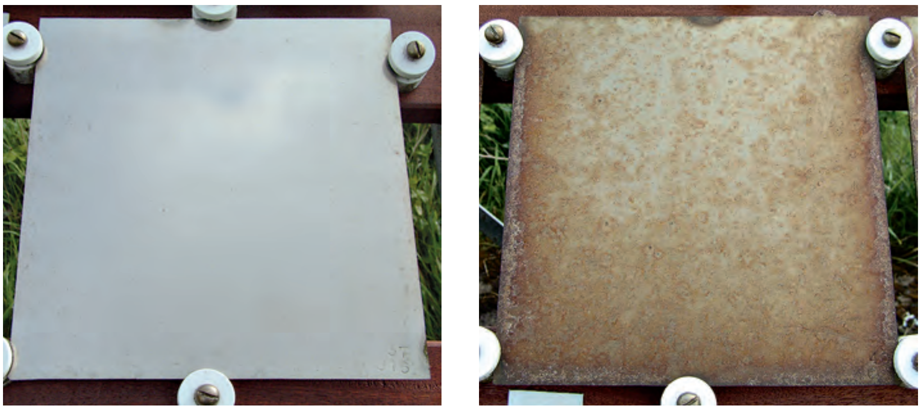
Intermediate level waste is placed into drums made from Type 316L stainless steel and filled with cement grouting to make a solid, secure wasteform for above ground storage in specially engineered facilities.

On-site atmospheric testing

In order to underpin the selection and long-term use of molybdenum-containing stainless steel, a unique program of atmospheric corrosion testing was initiated in 1991, using Type 316L S11 stainless steel, as well as a number of molybdenum-free grades. The samples were placed at test sites a short distance from the coastline. After 17 years exposure, the samples were retrieved and analyzed by radiography for signs of corrosion and other damage.

There was no evidence of corrosion or significant pitting damage in the molybdenum-containing sample, whereas stainless steel without molybdenum (409 grade was used in this example) showed significant staining, as shown in the photographs below. The test conditions are likely to be much more severe than any encountered in the engineered drum stores, therefore the results greatly increased confidence in the continued integrity of the drums during above ground storage.

The long-term future of nuclear power remains uncertain, but safely dealing with the back end of the fuel cycle from current and historic operations is a growing priority. Dry storage is an increasingly common mid to long-term management option for many operators, and molybdenum is playing a role in increasing the long-term performance of stainless steel used in dry storage casks. Similarly, proving the viability of a long-term storage and disposal route for nuclear waste is essential to the clean-up program underway at Sellafield and many other nuclear sites. The extra degree of corrosion resistance imparted to waste drums through the addition of molybdenum is making an important contribution to reducing overall hazard. (Alan Hughes)



316L grade (left) and 409 grade (right) plates after 17 years exposure at Sellafield. © NNL