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MolyReview 1/2016

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Drinking water – Saving every drop

Most people take drinking water for granted, largely unaware of the vast network of pipes connecting the reservoir and treatment plant to the faucet. Life seems unimaginable without it, yet on average more than a quarter of the water distributed by utility companies never reaches a single customer.

Leaks and bursts from old pipes and loose or corroded fittings are mostly to blame. Worldwide, 25–30% of water is lost in distribution. In Europe, an average of 26% of water is lost; in other parts of the world, NRW rates of up to 70% have been recorded. In the U.S., two-thirds of a $384 million, 20-year capital investment program for public water systems has been earmarked for improvements in water distribution systems.

Molybdenum-containing stainless steel is an ideal replacement material for older pipes made from lead, iron or plastics. It can dramatically reduce the number of repair cases and overall water loss, especially in seismic areas where the risk of damage to underground piping is greater.

The loss of treated water to leakage before it reaches the customer is not just wasteful, it is costly. It requires extra water processing plants and more treatment chemicals as well as more energy to pump the water to where it needs to go. Add to that the unnecessary depletion of water resources and the destruction of natural habitats to build new catchment facilities, such as dams and reservoirs, and there is a very compelling case for addressing losses, which goes far beyond saving money.

Non Revenue Water (NRW) can be defined as the water that a utility produces (or purchases) and distributes but which generates no income, essentially system input minus billed consumption. Unbilled or unauthorized consumption and meter inaccuracies account for a small proportion of NRW, but the biggest contributor is physical losses due to bursts and leaks.

Durable and resilient service piping

Upgrading aging steel, lead or plastic water pipes can dramatically reduce water leakage, particularly in the service pipe connecting the water main to a property, where some 95% of leaks are typically found. Problems often go undetected for months or years, meaning that even small leaks can be responsible for the loss of millions of liters.

Replacing old pipes is the obvious solution, but with what? To provide hygienic drinking water over a long service life, pipes must be manufactured from a material offering several distinct advantages over the steel, iron and plastics versions. Corrugated stainless steel piping dispenses with the numerous elbows and fittings needed in traditional pipes to connect the water main to the meter. Joints are vulnerable to the aging of gaskets, earth movement, vibration from traffic above and seismic events, all of which can cause them to leak over time. Using corrugated stainless steel piping has been shown to reduce the potential for leaking by 75–80%. ›

Publisher:
International Molybdenum Association
454-458 Chiswick High Road
London W4 5TT, United Kingdom
www.imoa.info
info@imoa.info
+44 20 8747 6120

Editor in Chief:
Nicole Kinsman

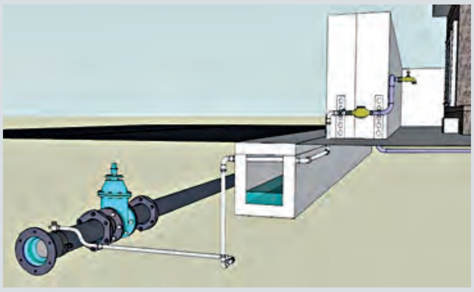
Managing Editor:
Curtis Kovach

Contributing Writers:
Alan Hughes (AH), Alenka Kosmac (AK), Curtis Kovach (CK), Karlee Williston (KW), Thierry Pierard (TP)

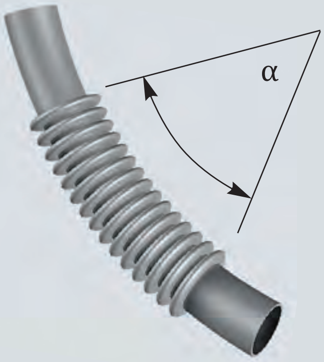
Layout and Design:
circa drei, Martina Helzel

Cover photo:
Tokyo, part of the largest metropolitan area in the world with over 30 million inhabitants, has replaced all service pipe with Type 316 stainless steel and virtually eliminated water loss. © Thomas La Mela/Shutterstock.com

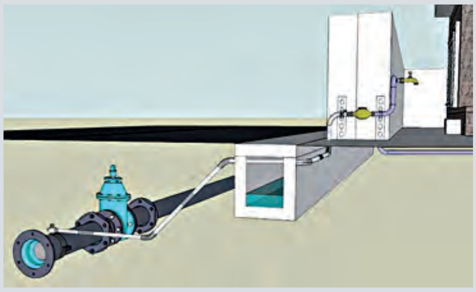
Traditional connections
- each elbow has two joints
- joints are prone to leakage or can fall off during earthquakes



Taipei example: With elbows – 15 connections between the water main and the meter



Corrugated pipes
- reduce number of connections
- reduce the rate of leaks
- are bendable or deflectable during an earthquake



With corrugated pipes – 3 connections
The potential for leakage is down to 20% of the traditional system.

Molybdenum-containing stainless steel also provides other benefits:

- **Durability** – Corrugated stainless steel piping is designed to last for 100 years or more without replacement or repair.
- **Strength and ductility** – Strong pipes which are capable of withstanding great pressure from the surrounding soil and heavy trucks passing on the road above and which will 'bend before breaking', even during seismic events. The high strength also allows for a stronger connection to the fittings at either end.
- **Fitting** – Corrugated stainless steel pipe can be simply bent to fit and can be easily and quickly installed, saving time and money.
- **Resilience** – Strength and flexibility combine to protect the pipes even from accidental mechanical damage, for example by a digger.
- **Corrosion resistance and protection** – greater resistance to corrosion and aging from the water itself, from treatment chemicals and from the surrounding soil.
- **Hygiene** – Stainless steel is essentially inert in water, with negligible leaching of alloying components, and therefore not affecting the quality of the drinking water.
- **Recyclable** – Stainless steel is 100% recyclable, further reducing environmental impact and enabling a proportion of the original cost to be recovered at the end of service life.

Near-zero leakage in Tokyo

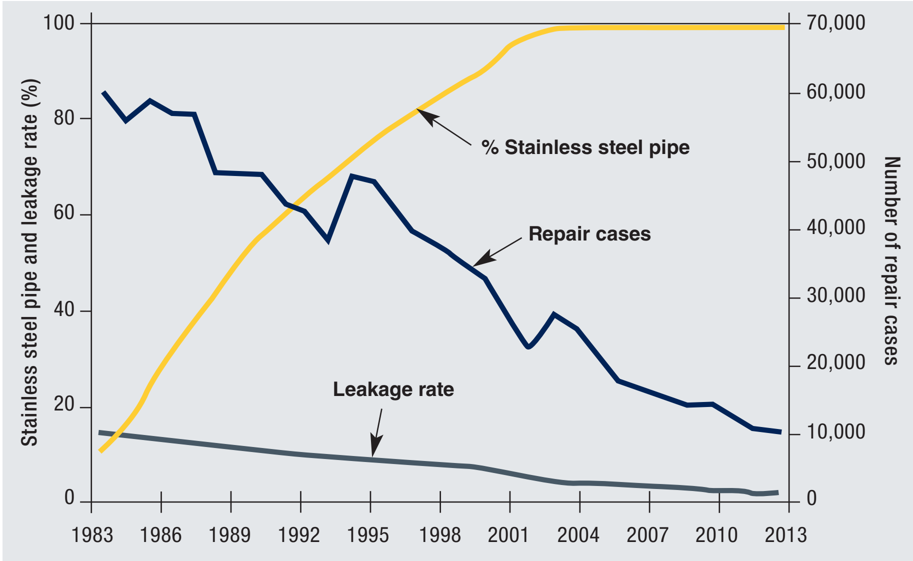
Like any city, Tokyo uses a lot of water. Rapid economic growth in the second half of the 20th century greatly increased water demand as an influx of population and industries swelled the metropolitan area. Even though demand has slowed thanks to new water-saving technologies, the City still has an incredible thirst, with more than 1.5 billion cubic meters of water distributed in 2013. ›

Installation of corrugated Type 316 stainless steel service pipe in Tokyo. © Tokyo Waterworks

The potential for leakage in a network with more than two million connections in one of the seismic hotbeds of the world is massive, yet water loss is only a little over 2%. The reason is that in the early 1980s, the water authority began a water-loss reduction program to replace all the lead service piping in the network with Type 316L stainless steel, and since 1998, with corrugated Type 316L stainless steel pipe. They also replaced the cast iron water mains with seismic-resistant ductile iron piping, reducing the vulnerability of the transmission infra-structure to earthquakes.

The authority furthermore introduced a comprehensive leak detection and fast repair regime, using a variety of new technologies to detect and fix leaks very quickly, often before they become apparent. This increased vigilance, coupled with the replacement program, saw Tokyo's NRW fall from 17% in 1983 to 2.2% in 2013.

To put this into context, Tokyo has reduced annual water leakage by nearly 150 million cubic meters since the early 1990s. The cost savings associated with the reduced water loss combined with the savings due to the drop in repair cases amounts to hundreds of million dollars per year for the Tokyo Waterworks.



The relationship between percentage of service pipe replaced with stainless steel (yellow), leakage rates and number of repair cases in Tokyo's water system since 1983.

People lining up to collect water from tank truck in Kolkata, India. © istockphoto.com/ookpiks

Drought averted in Taiwan

A similar program to replace service piping and cast iron mains was undertaken in Taipei, where the water department distributed 0.8 billion cubic meters of water in 2013, over a network with some 310,000 connections. The program began in 2003 after a severe drought in the previous year which brought intermittent water supplies to the Taiwanese capital over a 49-day period.

Leakage rates were analyzed in 450 district metering areas within the city, revealing that 40% of the areas were losing half of their water or more before it reached consumers. A detailed analysis of the repair cases showed that while polybutylene pipe accounted for only 3% of the network it had 28% of all leaks. Some 90% of all problems occurred in plastic pipes, with the vast majority (83%) caused by cracking. As in Tokyo, an enhanced regime of leakage detection and swift repair was introduced.

The ongoing program has so far replaced 35% of service piping of various materials with corrugated Type 316L stainless steel pipe. The result was a 10-percentage points drop in water loss, from 27% in 2003 to 17% in 2014. In terms of water volume, losses in Taipei were even greater than in Tokyo, at 365 million cubic meters in 2005. In 2014, with the replacement program less than half complete, leakages had already been reduced to 219 million cubic meters, a reduction of 146 million cubic meters, resulting in significant cost savings.

More importantly, a drought more extreme than the 2002 event which precipitated the pipe replacement program occurred in 2014, with 13% less rainfall than during the previous drought.

However, the vast improvement in leakage rates achieved since 2003 meant that there was no interruption to the water supply. In fact, more water reached the customers even though less was distributed in total.

Water is a fundamental human need which can't be substituted with anything else. On average, we drink four liters a day in one form or another, and use much more in our everyday lives. Security of supply is a prerequisite for the sustainable growth of our towns and cities. Replacing leaking service piping with molybdenum-containing stainless steel is an investment in the future. This also makes economic and environmental sense in the present day, as these examples clearly demonstrate. (AH)

Propelling the boating world

The propeller shaft may be the most important component of any motorized vessel. It drives the propeller, hour after hour, day after day. Molybdenum provides improved strength and corrosion resistance in several high-performance stainless steel grades used in demanding shaft applications.

The propeller shaft is a critical component of any motorized vessel. It must withstand high stresses when transmitting the motor's power to the propeller, as well as any impact should the propeller strike an object. It must also resist corrosion in marine environments. Today's vessels use a variety of highly sophisticated propulsion systems and a range of advanced shaft materials, depending on the vessel's operating conditions. Stainless steels are the most common shaft materials, available in several grades.

Shaft design

The primary considerations in shaft design are the selection of the correct shaft diameter and shaft material, given the power of the vessel and the rotational speed of the shaft. The shafts of large, slow-moving cargo vessels turn at only a few hundred revolutions per minute (rpm) but the motors are very powerful so they need shafts up to 1 meter in diameter. At the other end of the range, small fishing boats with electric motors may have a shaft of only 1 centimeter in diameter. For fast patrol boats or yachts, where shafts turn at several thousand rpm, larger diameters are necessary. Suppliers to the pleasure-boat and workboat industries commonly stock sizes in the range of 2 to 18 centimeters.

Manufacturing

Good shaft performance requires precision and attention to detail during manufacturing. Fatigue resistance is of primary importance. This requires good straightness to minimize vibrational stresses and defect-free surfaces to minimize stress concentrations. The steel mill must deliver a shaft to the fabricator that not only is straight but also low in residual stresses that might otherwise cause the shaft to change shape during machining. Fabricators must produce good roundness, a precise diameter and taper for mounting the propeller, and keyways free of sharp corners which increase stresses. The finished shaft must have low residual stresses. Only such a shaft can withstand fatigue over the many hours of cyclic stress during its life.

Material choices

Common shaft materials range from carbon steels to very high-performance molybdenum-containing stainless steels. Each material serves specific needs over the broad spectrum of boating applications.

The waters where the vessel operates and the vessel's pattern of use play an important role in specifying a shaft material. Carbon steel shafts, fitted with sleeves and frequently covered in fiberglass to protect them from corrosion, are routinely used in large ocean-crossing vessels because they are cost effective and size, weight and agility are less important. On the other side of the range, sporty pleasure yachts, which can be docked for long periods of time in corrosive, polluted waters, require high-strength shafts with maximum corrosion resistance, i.e. molybdenum-containing duplex or austenitic stainless steels. Thanks to their high strength, these steels permit reductions of shaft, support, and seal dimensions that simultaneously reduce weight and drag, improving vessel performance and efficiency. It is important to note, that despite their good corrosion resistance, most of these grades are not sufficiently resistant to seawater, so they need to be cathodically protected with sacrificial anodes.

The fabrication of boat shafts requires large, sophisticated machinery to maintain the tight tolerances necessary. © Schaffran Propeller + Service GmbH

Duplex stainless steels, like the workhorse 2205 grade containing 3% molybdenum, not only deliver high strength and corrosion resistance, they also resist abrasion and erosion at high flow rates. Because of these advantages, European companies increasingly select duplex stainless steel propeller shafts and almost every commercial and pleasure boat built in Australia uses them. Duplex grades are particularly useful where high acceleration and heavy-duty operation is expected, such as in coast guard vessels and mega yachts.

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The “Richard Dixon” is from the latest model series of fast response cutters operated by the US Coast Guard. Each boat uses two large alloy 22 propeller shafts. © US Coast Guard, Mark Bamey

Typical properties of steel and stainless steel boat shafting alloys

Name	1018 Steel	Type 316	Alloy 2205	Alloy 2507	Alloy 19	Alloy 22	Alloy 17-4PH
Type	Carbon Steel	Austenitic	Duplex	Duplex	Austenitic	Austenitic	Martensitic
Typical yield strength (MPa)	220	290	500	550	860	860	860
Cr	–	16.0–18.0	22.0–23.0	24.0–26.0	18.0–20.0	20.5–23.5	15.0–17.5
Ni	–	10.0–14.0	4.5–6.5	6.0–8.0	8–10.5	11.5–13.5	3.0–5.0
Mo	–	2.0–3.0	3.0–3.5	3.0–5.0	–	1.5–3.0	–
N	–	–	0.14–0.20	0.24–0.32	0.20–0.30	0.20–0.40	–
Toughness	moderate	good	moderate	moderate	good	good	moderate
Corrosion resistance	low	moderate	good	excellent	moderate	good	minimal
Cost	low	moderate	moderate	high	moderate	high	moderate
Typical application	Ships and large commercial boats; shafts require protective sleeves	General purpose, light duty, brackish and fresh waters	Pleasure boats, premium and large yacht applications, commercial and workboats	High-end luxury yachts	General purpose yacht applications	Premium and large yacht applications, commercial and workboats	Commercial boats and wetted shafts in outboard and stern drive applications

When low drag is important, higher strength nitrogen-alloyed austenitic grades, such as alloy 22 with a minimum of 1.5% molybdenum, are used to reduce the required shaft size. One disadvantage of this material in shipbuilding is that it is very tough to machine. An alloy 22 shaft may take twice as long as the same job in duplex stainless steel. It is sometimes described as the material of choice for high-horsepower and special-purpose military vessels. North America as a whole is taking this design approach, with high-strength, austenitic grades dominating high-end and severe shaft applications.

Both types of stainless steels have very good shafting properties, so it is interesting to contemplate why usage patterns vary around the world. The key is probably availability. High-nitrogen austenitic grades were developed in North America decades ago, where they have become a de facto standard. Duplex stainless steels are generally not available from stock there. Conversely, duplex stainless steels have been developed in Europe and are to date the most popular in that region, so their availability is good and they are more dominant.

Alternate materials are available to fit specific circumstances. The molybdenum-free martensitic stainless steel 17-4PH performs well for workboats and fishing boats in corrosive bay and river waters because their near-continuous operation keeps shafts clean from fouling and they have good strength and toughness. ›

Boat shafts require precise machining of the taper where the propeller is attached.

This work boat has two 90 millimeter diameter 2205 duplex stainless steel shafts. It is designed to bring crews to offshore wind farms. © Clements Engineering

Fresh water yachts, which are docked much of the time, require a corrosion resistant material such as molybdenum-containing Type 316 stainless steel, because deposits can build up during inactive times, leading to crevice corrosion in lower grades. In this case sacrificial anodes are not necessary.

Summary

Molybdenum plays an important role in recreational, commercial, civil and military boat and ship design by improving the strength and corrosion resistance of high-performance propeller shafts used for these vessels. Molybdenum-containing high-strength austenitic and duplex stainless steel grades deliver the strength, toughness and corrosion resistance necessary for a good propeller shaft. These alloys allow many kinds of vessels to operate efficiently, safely and reliably the world over. (AK, CK)

A stomach of (stainless) steel

Every day large amounts of food waste accumulate in restaurants, food courts, hotels, supermarkets, hospitals, stadiums and convention centers. Typically this volume goes into the waste bins and has to be hauled away for off-site disposal. Ultra-modern biodigesters, machines with a "stomach" of molybdenum-containing stainless steel, are revolutionizing the way such waste is handled in institutional settings.

The United Nations Food and Agricultural Organization (FAO) estimates that 30% of the world's food supply is never eaten due to loss and waste. About a third of that total is due to waste, amounting to about 4 million tonnes of food annually with a carbon equivalent footprint of about 1.1 billion tonnes of CO_2 equivalent. It accounts for agricultural water consumption of 80 cubic kilometers (about the same amount contained in Lake Geneva), and needs about 0.5 billion hectares of land, or about 10% of the world's agricultural land area, to grow it. While the ultimate economic, environmental, and resource-allocation goal is to greatly reduce these numbers, it is a difficult and long-term task. In the interim there is a great need for strategies to deal with food waste in an environmentally responsible fashion.

A mini waste-treatment facility

The current approach to waste food disposal is landfill or incineration. This consumes fuel for transport, generates › vehicle emissions and, in the case of landfills, produces methane emissions and taxes increasingly limited capacity. For institutions that generate large amounts of food waste, it also means additional costs to support waste collection and landfill fees.

On-site biodigesters provide an economic alternative to landfill disposal. Modern digesters use environmentally benign enzymes and bacteria to break down food waste to a liquid that is compatible with gray water (waste water without fecal contamination), sewer systems and sewage treatment facilities. This allows for on-site disposal of waste through the building drain, saving businesses the cost of hauling to a landfill, an incinerator or a composting site. Typically the investment cost of the digester is recovered within a few years.

The biodigester is made almost entirely of stainless steel. © BioHiTech America

The critical element: molybdenum

The digester itself is not so simple a machine as one might expect. Because it must continuously digest high volumes of raw meats, fibrous vegetables and materials not so easily liquefied (egg shells, for example), it requires an extremely durable vessel. The digester's internal lining must withstand the corrosive properties of its contents, including the microorganisms that expedite the digestion process and the chemicals produced by their action. One manufacturer, BioHiTech America, builds its Eco-Safe Digester® using Type 316 stainless steel for the reactor, the main component comprising about 70% of the machine's weight. Thanks to the 2% molybdenum content of Type 316 stainless steel, the durability of the reactor is significantly better than earlier designs made from molybdenum-free Type 304 stainless steel. Even heavy users have reported no material-related problems with the new reactor.

The digester is unique in its ability to record and store information remotely. Because it is equipped with an internal scale, users can weigh input foods and identify the source of the waste. The information is stored in the cloud and allows businesses to better measure their performance, detect sources of food waste, and take steps to reduce or eliminate waste.

Biodigesters reduce the amount of waste that has to be transported to landfills or incineration plants. © shutterstock/Shutterlist

Benefit for all

Biodigesters help to reduce Earth's carbon footprint, conserve scarce landfill volume, and keep operating costs low for kitchens that prepare large quantities of food. Molybdenum-containing stainless steel plays its part to assure digester durability and contribute to efficient processing of food waste streams. This is just another example of the many ways that molybdenum contributes to better stewardship of resources. (KW)

Note: The author wishes to thank Ms. Kristie Galvani of Rubenstein Public Relations for providing much of the information used in the preparation of this article. (kgalvani@rebensteinpr.com)

One hundred years of safety

A gigantic airtight enclosure is under construction at Chernobyl. It is designed to survive temperature extremes, earthquakes and tornados and prevent corrosion in order to protect the environment from the encapsulated but still dangerous reactor. Clad in molybdenum-grade Type 316L stainless steel, the structure will safely contain radioactive dust and debris for more than a century.

The meltdown of the Chernobyl nuclear reactor Unit 4 in 1986 will long be remembered as one of the largest man-made disasters in history. It produced and broadly distributed severe radioactive contamination. The threat of additional dispersion was ameliorated soon after the disaster by constructing a large sarcophagus-like enclosure (the "Object Shelter," or OS) around the reactor to prevent further release of radioactive particles.

Unfortunately, weather and corrosion have degraded the steel and concrete OS since it was built nearly 30 years ago, and there is now danger that it might collapse. The international community has taken on the task of securing the site with a new permanent and much safer confinement structure, the New Safe Confinement (NSC). This project is being funded by the Chernobyl Shelter Fund at the European Bank for Reconstruction and Development, which raised €1.3 billion as of November 2015. When finished in 2017, it is expected that the project will have cost more than €2 billion and will have over 40 nations and organizations as contributors to the fund.

The challenges for this unusual project were clear: to safely confine radioactive dust and debris that might be released in the case of the OS' failure; to eliminate the need for human maintenance of the structure because of the dangers posed by radioactivity; and to ensure that the structure could withstand without damage, temperatures ranging from -45°C to 45°C, a Class 3 tornado (a once-in-a-million-year occurrence) and an earthquake with maximum intensity of class 6 on the MSK64 scale (a once-in-10,000-year occurrence). The NSC also had to provide the capability to safely dismantle unstable reactor parts and remove radioactive waste and corium (solidified magma made from melted fuel and internal components) from the enclosed reactor. Furthermore, it would have to last 100 years to allow time for development of as-yet untested technologies to remove the radioactive debris.

The new structure – a monumental challenge

The NSC looks amazingly like a pre-WWII Zeppelin hangar. The stunning arch-shaped frame alone weighs 25,000 metric tons, and when fully equipped the building will weigh 31,000 metric tons. It stands 108 meters high, 162 meters long and 257 meters wide. The immense structure encloses a volume of about 3 million cubic meters, equal to that of London's O2 arena. The mammoth structure is taller inside than the Statue of Liberty, and could contain Notre-Dame de Paris or London's St. Paul's Cathedral. The finished structure will weigh nearly as much as four Eiffel Towers! To further complicate matters, the entire building had to be constructed about 200 meters away from the reactor buildings to limit workers' exposure to radiation, and will need to be slid over the existing OS and associated structures when finished. While much of the component fabrication could be accomplished off site, site preparation, erection, outfitting and placement has to be done on site with all its related radiation hazards.

Primary goal – prevent release of radioactive particles

The innovative arch structure uses a 12 meter-thick, three-dimensional lattice frame made from structural steel tubes. The OS is strictly confined by the NSC thanks to stainless steel cladding that completely wraps the arch both inside and outside of the lattice. The frame creates a 12 meter-wide annular space between the inner and outer skin. To ensure that interior air will not leak to the atmosphere, the annular space will be maintained under slight overpressure, while the volume under the arch will be maintained under negative pressure. This way, the annular space provides additional protection against leakage of contaminants.

Clad metallic walls close off the arch on each end. On the east end, the 4 meter-thick wall is contoured to closely fit the outline of the existing reactor building. When the structure is in place, closure panels attached to the wall will be remotely positioned to seal the wall. On the west end, an 8 meter-thick wall closes the open space under the arch. Both end walls hang from the arch structure so as not to transfer any load to existing structures. A confinement and dismantling information and control center will be located outside the west wall and adjacent to it.

Preventing corrosion

Dehumidified air will be constantly blown into the annular space to maintain the relative humidity below 40%. The combination of controlled ventilation and pressurization will prevent corrosion of the structural steel lattice from initiating. Both walls will employ the same internal atmosphere-control measures used in the annular arch space.

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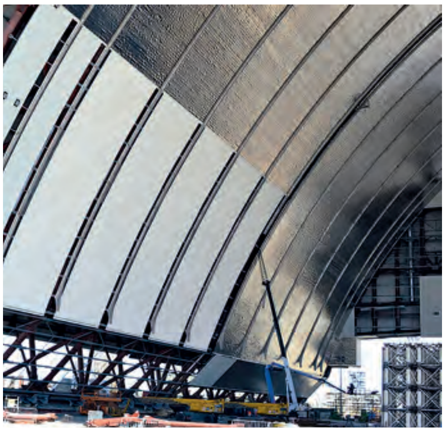
The people installing the interior cladding are dwarfed by the immense arch structure. © ChNPP



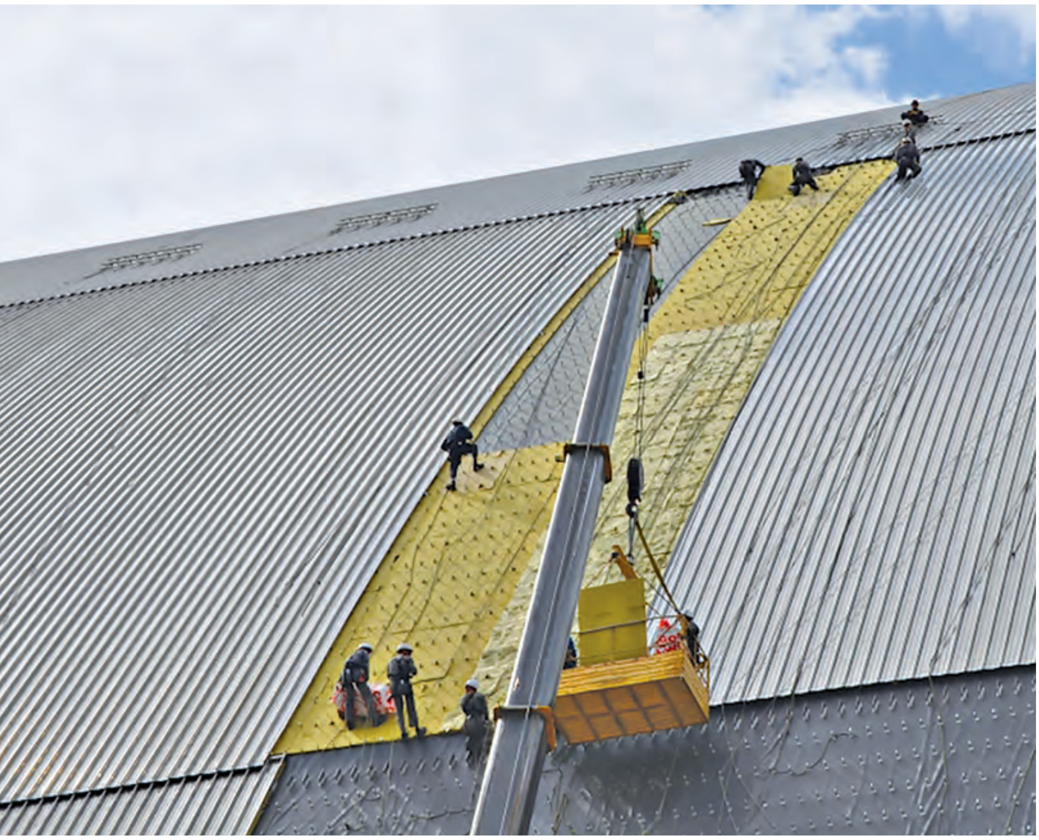
Installation of the internal cladding. © ChNPP

The arch frames are made from four hundred 813 mm-diameter, 12–40 mm-thick S355 carbon-manganese round steel tubes of a quality used in offshore oil rigs. Tubes are welded to gusset plates to form nodes that are connected by approximately 560,000 tension-controlled bolts. The lattice components have both an initial anticorrosion coating and a supplemental epoxy coating for corrosion protection.

The stainless envelope

As spectacular as it is, the details of this impressive lattice construction will be completely hidden for more than a century because it is covered by the stainless steel cladding inside and out. Stainless steel was a natural choice given its durability, high corrosion resistance and mechanical strength.

The arch's interior skin is Type 304 stainless steel, a non-magnetic grade used to minimize radioactive dust accumulation that would impair accessibility to dismantle reactor components. The interior surface required 80,000 square meters of 0.5 mm thick stainless steel sheets. The panels are tightly fitted to a galvanized deck. No ribs are present in the panels in order to further reduce dust collection. Tape seals and fire- and radiation-resistant silicone mastic ensure that the interior wall is airtight. Interior panels have a highly reflective bright-annealed finish to enhance brightness inside the building. The interior cladding requires no insulation, but the exterior surface employs a complex four-layer insulation package to meet stringent specifications.



Mountaineering skills were necessary to install the Type 316L stainless steel exterior cladding. © Novarka

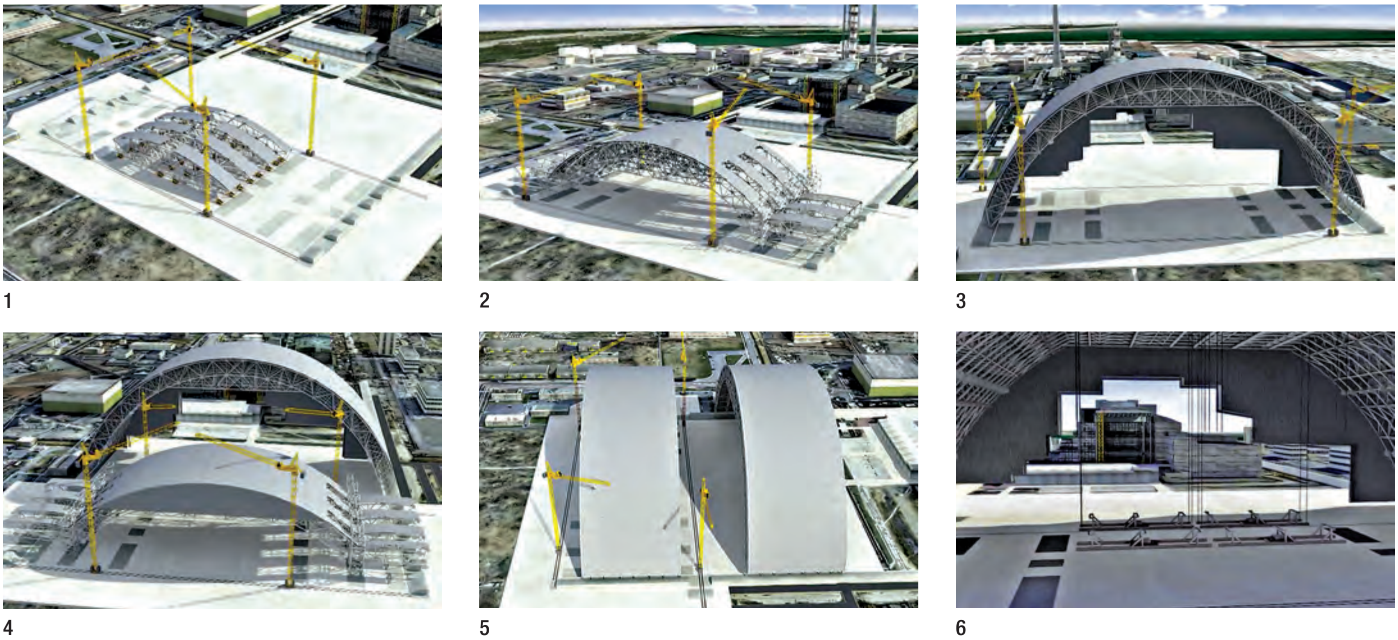
The design team chose molybdenum-grade stainless steel for the exterior skin. This surface is clad with 88,000 square meters of 489 mm wide 0.6 mm thick Type 316L stainless steel sheet profiles. Choosing Type 316L with 2% molybdenum for enhanced corrosion resistance ensured the required durability for a cladding with a 100-year life expectancy.

The stainless steel was annealed and pickled to create an evenly matte exterior finish in order to minimize reflections that might hamper the vision of pilots flying within view.

It was supplied by Aperam and delivered to the worksite by Kalzip in 1,000-meter coils. The Type 316L stainless steel was roll-formed on site into 100-meter long profiles for the roofing and 50–70 meter long profiles for the cladding of the eastern and western walls. The system allowed the forming of up to 200 square meters per day. After a profile had been positioned and clipped into previously installed Type 304 stainless steel fasteners called halters, the next profile was brought into position with the larger seam overlapping the smaller one. Fasteners were mounted through the water-proofing membrane by means of Type 316L self-tapping screws. Finally, a special seaming machine crimped all profiles to each other over their entire length.

Construction and assembly

Ongoing radioactive emissions made it necessary to build the new containment structure at a safe distance of about 200 meters from the damaged reactor ❯



1: Assembly of upper section of first half-arch. 2: Assembly of lower section and connection to upper one. 3: Lift first half to final height of 105 meters. Eastern wall is installed. Completed first half-arch is moved to waiting area to make room for assembly of second half-arch. 4: Assembly of second half-arch. 5: Connect two halves to form the complete arch. 6: Assembly of overhead bridge cranes and lifting in place 85 meters above. They are intended for dismantling the old sarcophagus and removing the debris of the damaged reactor. © Novarka

building. Half-arches were fabricated and preassembled on the ground in this area and outer insulating components as well as the cladding were installed at that time. Each half was then connected as the arch structure was completed. This process required a number of carefully planned steps as outlined in the graphics above.

How to move a monument

During site preparation, carefully aligned concrete beams were constructed to provide "rails" to move the structure on specifically designed and synchronized "skid shoes". In March of 2014, the system was used when the newly completed east half-arch was successfully transferred 300 meters to allow space for the assembly of the west half-arch. In July of 2015, the west arch cladding was completed and in August the two halves were joined with nearly 1,000 bolts and sealed. Once it is completed, the new containment will be moved on these rails to its final position above the old sarcophagus and the Unit 4 building.

While the accomplishments to date are truly impressive, important work remains to be done. Internal components must be fitted to the structure; the completed arch must be moved to its final position over the OS and its associated buildings; end panels must be completed and sealed; and the required ancillary buildings must be constructed to manage and control NSC systems. The project is not scheduled to be complete until late 2017, but all indications are that it will be an impressive success when finished. In this massive structure, Type 316L stainless steel will have helped to ensure a safe and contained environment for the next century. (TP)

The two half-arches are joined to complete the building before it will be moved over the damaged reactor site. © ChNPP

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. (AH)

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

IMOA news

New publications

Team Stainless has published a study confirming the continuing safety of stainless steel in food preparation. This follows the issue of a new Council of Europe guideline on food contact materials. The guideline defined specific release limits for metals and specified a new, more aggressive test.

Team Stainless, of which IMOA is a founder member, commissioned the KTH Royal Institute of Technology in Sweden to independently test seven grades of stainless steel, including the molybdenum-bearing 316 grade, in accordance with the new protocol.

The research demonstrated that all of the grades passed the new test for the relevant metallic elements of stainless steel. The report was launched with a communication campaign in November and can be downloaded at http://bit.ly/1HEzL5V.

IMOA has also published two papers in the International Journal of Life Cycle Assessment. The first, 'IMOA life cycle assessment program and perspectives on the LCA harmonization effort', reviews an initiative to harmonize metal-related LCAs. The second, 'Vehicle lightweighting through the use of molybdenum-bearing advanced high-strength steels', examines the environmental impact of various grades in a production vehicle. Both papers are available to download free of charge at http://bit.ly/1P4xfOU.

AGM 2015

The South American city of Santiago provided the venue for IMOA's 27th Annual General Meeting, kindly hosted by MOLYMET. The event, held in September 2015, attracted some 140 delegates over the two-day meeting. IMOA President Carlos Letelier noted the success of the Association in becoming the voice of the industry since its foundation in 1989 and called upon members to support the Secretary General and the Executive Committee in their efforts to recruit further companies. He paid tribute to the work of members engaged on various committees and working groups in addition to the dedication of its staff members.

Amongst the varied presentations was an overview of the world economy by Felipe Larraín, former Finance Minister in the Chilean government; an analysis of the effects of the recent changes in the Chinese economy; and a review of the effects of the oil price drop on the molybdenum market.

IMOA hosted a dinner at Castillo Hildago which was reciprocated on the following evening by a dinner reception held in MOLYMET's corporate grounds. After the close of the AGM, delegates took the opportunity to visit the Sierra Gorda molybdenum mine.

Guests enjoying a dinner reception hosted by MOLYMET during IMOA's 27th AGM in Santiago, Chile.

Website education section launched

A new education section has been developed for the IMOA website. Designed principally for those studying or newly qualified in architecture or mechanical, structural and civil engineering, the education pages host links to relevant content on the properties and applications of molybdenum-containing materials.

Users can choose between 'engineering' and 'architecture', with subject areas broadly matching a cross-section of university syllabi. Each area contains links to further pages and resources.

A total of more than fifty pages and indices are cross referenced, covering stainless, duplex and alloy steels and their uses in architecture, building, construction and mechanical engineering. The education section can be accessed via a link on the homepage or directly through www.imoa.info/educational