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Super Austenitic Alloy N08367 Service Water Piping Review

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ABSTRACT

The recent spike in oil prices has spurred research for stable energy sources that do not rely on foreign suppliers. Nuclear energy has a renewed focus which requires a closer look at the materials of construction.

Various types of corrosion in nuclear service water piping systems have limited the use of general stainless steels. Due to highly corrosive environments, general stainless steels are being replaced by super austenitic alloys with increased molybdenum content.

Examples, such as microbiologically induced corrosion (MIC), have caused failure of 304L stainless steel. Alloy UNS N08367 has been a replacement for 304L stainless steel in main and auxiliary service water piping systems. The improved performance of this alloy has promoted its use in intake screens, piping, and precipitators.

With the current search for more efficient and independent power generation; nuclear power plants have incentive to improve the process and equipment for both existing and new power plants. Globally, the push for alternative power requires better designed plants to withstand the ever increasing corrosive environments. This paper describes current corrosion issues of general 300 series stainless steels in nuclear power plants. An in depth analysis shows how use of the 6 percent molybdenum alloy N08367 in various nuclear applications reduce maintenance costs, increase quality, and improve safety.

The conclusion of this paper and presentation is that 6 percent molybdenum alloys provide enough longevity in to justify increased material and fabrication costs. This paper will show how this development in alloy selection has proved successful in previous nuclear systems as well as the next generation of nuclear reactors.

Keywords: N08367, nuclear, service water piping, microbiologically induced corrosion (MIC), nuclear power plants, stainless steel

INTRODUCTION

There is a renewed interest in providing nuclear power as an alternative source of power. With this renewed interest, there is a strong drive to find suitable materials able to withstand harsh environments with little to no maintenance. It has been some time since a new nuclear power plant has been completed in the U.S. This gap in production has lost experience and familiarity with nuclear plant designs and the alloys involved. This paper is a review of how AL-6XN® [(1)] Alloy (UNS N08367) has been used successfully in previous designs and how it can be further developed with the next generation of nuclear power plants. More specifically, alloy N08367 has been utilized in service water piping, which is intended to transfer heat away from structures as a safety service. In service water piping, superaustenitic alloy N08367 has proven to be a drastic improvement over other options, such as 304L and 316L stainless steel.

Superaustenitic alloy N08367 is a high nickel alloy with nominal chemistry including 6.3 weight percent molybdenum. A complete chemistry range is shown in Table 1.

The increased chromium and molybdenum content compared to 300 series stainless steels greatly increases the pitting and crevice corrosion resistance. In the area of service water piping in nuclear power plants where 300 series stainless steel fail due to crevice corrosion or microbiologically induced corrosion (MIC), the N08367 alloy is many times better to be a suitable alternative to 300 series stainless steel. This paper analyzes the successes of N08367 in service water piping systems within existing nuclear power plants.

GLOBAL DEMAND FOR NUCLEAR POWER

A push for more reliable energy resources and reduced greenhouse gas emissions has increased the global demand for nuclear power. The demand for nuclear energy requires additional engineering to provide safer and more efficient nuclear plant designs. New plants are being built with better designs and better materials based on experience from previous nuclear power plants. The U.S. is in a good position to take advantage of existing experience with nuclear power plants and implement improved designs into the growing demand for increased electric power.

The Nuclear Energy Agency has projected that by the year 2050, the global nuclear capacity will have at least doubled and may increase by as much as five times the current capacity. See Figure 1. Many countries have already made significant investments in nuclear power.

The U.S. Department of Energy has predicted similar growth domestically. "Electricity demand in the United States is expected to grow sharply in the 21st century, by almost 50 percent by 2030 according to the Energy Information Administration (EIA), requiring new generation capacity." [1] See Figure 2.

[(1)] AL-6XN® is a registered trademark of ATI Allegheny Ludlum

NUCLEAR POWER PLANT DESIGN

New advanced nuclear power stations are currently being designed for 60 years, versus 40 year designs for existing nuclear units, although many existing plants have received 20 year extensions. Several new nuclear power plant designs were submitted to the Nuclear Regulatory Commission (NRC). The Westinghouse Advanced Passive Pressurized Water Reactor (AP-1000[(2)]), the General Electric (GE[(3)]) Economic Simplified Boiling Water Reactor (ESBWR[(4)]) and the Areva EPR[(5)] were submitted for approval[1].

Figure 3 shows a typical Advance Boiling Water Reactor (ABWR) plant design. All new nuclear power plant designs in the U.S. include the use of service water piping as a method for cooling hot sections of the reactor. The service water piping is also used as a fire protection system in the case of emergencies.

SERVICE WATER PIPING DESIGN

Service water piping is intended for use in general cooling of water generated from the boiling water reactors. This general cooling is ongoing during normal operation. The consistent flow of the water limits the possibility for microbiologically induced corrosion (MIC). Either a joint or separate service water system is designed for emergency use, such as a fire. If the emergency service water system is a separate unit, it is only used during emergencies. Prior to emergency use, the separate service water is stagnant which, increases the likelihood of MIC attack. If corrosion occurs during these stagnant periods, the emergency service water piping may become unusable due to either failed sections of piping or fouling from excessive corrosion.

In addition to the risk of MIC attack, service water piping can also be attacked by chloride in the service water. The water supply in the service water piping can be either a closed loop or open loop system. The closed loop system re-circulates the service water. The closed loop system generally has less corrosive environments than the open loop system. . The open loop system uses water from rivers, lakes, or oceans. The corrosion of the service water piping is dependent on the water source. Nuclear power plants using service water from oceans have much higher potential of corrosion failures with 300 series stainless steels. The high levels of chlorides combined with high operating temperatures can cause chloride stress corrosion cracking.

CHLORIDE STRESS CORROSION CRACKING

The supply water in open looped systems varies based on the location of the nuclear power plant. Nuclear power plants near the ocean use seawater for cooling service water. The seawater is extremely corrosive to 300 series stainless steels and produces a large potential for chloride stress corrosion cracking at elevated temperatures. Chloride stress corrosion cracking penetrates the alloy through the grains causing branching cracks. The chloride stress corrosion cracking can cause sudden failure and leakage. This type of failure occurs when high levels of chlorides are combined with internal stresses in the material and relatively high

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[(2)] AP1000 is a trademark of Westinghouse Electric Company, LLC
[(3)] GE is a trademark of General Electric Company
[(4)] ESBWR is a trademark of General Electric Company
[(5)] EPR is a trademark of Areva Group

temperatures. Both 304L and 316L stainless steels failed U-bend tests in boiling 26 percent NaCl in less than 1,000 hours. Alloy N08367 is immune to cracking in this test[2]. If the temperatures are limited below 140°F (60°C), the chloride stress corrosion cracking can be controlled. In most nuclear service water systems the temperature is controlled to about 125-128°F (52-53°C), which is below the threshold for chloride stress corrosion cracking.

MICROBIOLOGICALLY INDUCED CORROSION (MIC)

Most service water systems operate intermittently and tend to be stagnant for weeks at a time. The stagnant water optimizes conditions for microorganism growth. Some sulfate-reducing bacteria will produce hydrogen sulfide. The hydrogen sulfide can cause sulfide stress cracking in carbon steels and other alloys depending on the hardness. Other bacteria actually form sulfuric acid which rapidly pits 300 series stainless steels. If the sulfuric acid concentration is high enough, even 22 percent chromium duplex stainless steels, such as UNS S32205 can pit. Figure 4 shows the isocorrosion curves for 316L, duplex and 6% molybdenum alloys in sulfuric acid[3].

Typically chlorine is added to the service water piping to control the biological growth. The reduced levels of bacteria limit the effects of MIC. Even though the chlorine limits the amount of MIC attack, the chlorine at high temperatures may cause corrosion similar to that of sodium chloride found in ocean fed service water piping systems.

POLYVINYL CHLORIDE (PVC) PIPIING

PVC piping has been approved for underground fire service in nuclear power plants. The UL 1285 standard now includes pipe and couplings made from polyvinyl chloride (PVC) for underground fire service. Piping that is 1-1/2 inch through 6- inch diameter may be ABS or PVC plastic pipe.

Although some instances allow the use of PVC piping for underground use, all above ground service water piping should be made of metal alloys. Even if PVC is used underground, it may be beneficial to use alloy N08367 for above ground sections that do not have approval for the use of PVC.

Other polymer piping such as high-density polyethylene (HDPE) is also limited to use underground. Although the corrosion resistance is excellent, the mechanical strength is very low. Because of its high thermal expansion coefficient it must be buried. Using alloys such as alloy N08367 allows for much thinner piping walls in both buried and above ground areas.

SAFETY CONCERNS

Many corrosion issues in service water piping are not apparent until after an emergency occurs. A stagnant service water system can induce MIC and chloride stress corrosion cracking in stainless steels. Even carbon steel piping has a potential of fouling due to sediment and corrosion buildup. If these corrosion issues go unnoticed prior to an emergency, the service water piping may be unusable during emergency situations.

N08367 CASE HISTORIES

304L replaced due to MIC: A nuclear generating station in southeastern U.S. selected alloy N08367 to replace 304L piping for the main and auxiliary service water piping systems. The previous 304L piping suffered MIC corrosion. The water was supplied from a fresh water man made reservoir. Water testing showed 3 ppm Cl^-, 6 ppm sulfates, 38 ppm total solids, a pH of 5, and a maximum temperature of 95°F (35°C). This service environment created optimum conditions for biological growth. The biological growth caused microbiologically induced corrosion. The 304L stainless steel did not have sufficient corrosion resistance against the MIC and eventually cracked to failure. The same piping was replaced with alloy N08367 to resist MIC.

The Salem Nuclear Generating Station of the Public Service Electric & Gas Company (PSE&G[(6)]), New Jersey, USA: Two 1,100MW units were put into service in 1977 and 1981. Despite regular maintenance, the service water piping had problems with corrosion. The cooling water consists of 3,800 ppm Cl^-, magnesium hardness 796 ppm ($CaCO_3$), calcium hardness 220 ppm ($CaCO_3$), sulfate 445 ppm, a pH of 7.1, and temperatures ranging from 35°F to 90°F (2°C to 31°C). The underground piping was concrete, the in-plant piping was carbon steel and the heat exchangers were 90/10 copper-nickel alloy. The carbon steel suffered corrosion at the weld seams where there were gaps in the lining. The copper-nickel alloy suffered severe pitting corrosion. Several alloys were chosen for testing. The testing included 316L stainless steel along with the 6 percent molybdenum alloy UNS N08367. Early crevice and pitting attack was noticed in the 316L samples, so they were removed from testing. From 1986 until the date of the case history (1994) there was no evidence of crevice or pitting attack in the N08367 alloy. The 6 percent molybdenum alloys were chosen as the preferred replacement material[4].

Calvert Cliffs. The two Pressurized Water Reactor (PWR) units at Baltimore Gas and Electric's (BGE[(7)]) Calvert Cliffs Nuclear Power Plant were originally built with 70/30 copper-nickel steam condenser tubing. As a result of leakage, both units were retubed in 1982: one with titanium tubing and the other with as-welded N08366 tubing. N08366 is the nitrogen-free predecessor of N08367. The added nitrogen in N08367 increases the strength and pitting resistance of the alloy. These units were examined in 1991 and 1992, and the results of that investigation were reported in 1994. The authors concluded that more than 95 percent of all N08366 tubes had no detectable degradation. Most of the attack was localized crevice corrosion, under deposits at the weld seam. The total number of tubes plugged for all reasons was only 2.0 percent. To follow up on this, the authors conducted seawater tests. Because N08366 material was then no longer available commercially, they investigated both N08366 and N08367 materials. Seawater tests were conducted at Wrightsville Beach, NC, using a variety of crevice conditions. In one set of tests, vinyl sleeves were applied over the tube OD for a distance of one inch from the end. Type 316 compression fittings were used to create metal-to-metal crevices and evaluate the risk of dissimilar metal crevice of the N08367. There were a total of 12 possible OD crevice sites (6 vinyl and 6 metal) per material condition tested. Portions of the tube IDs were coated with epoxy to evaluate another possible cause of crevice corrosion. The attack of these materials can be attributed to the severity of the crevice environment produced by the vinyl sleeve, which has resulted in attack of N06625 and even

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[(6)] PSE&G is a trademark of Public Service Electric & Gas Company
[(7)] BGE is a trademark of Baltimore Gas and Electric

N06022 material. Although the Type 316 compression fittings corroded badly, there was no attack of the adjacent N08366 or N08367 materials, indicating that dissimilar metal crevice was not a problem. Neither alloy exhibited any crevice attack under the epoxy coating.

Oskarshamn Nuclear Power Plant, Figeholm, Sweden: This coastal nuclear power plant used sea water for cooling in their service water piping. The high chloride levels in the seawater created a potential for chloride stress corrosion cracking in 304L and 316L piping. Due to the seawater supply, superduplex and 6 percent molybdenum alloys were chosen to resist corrosion. Alloys such as N08367 have been used in various seawater environments well above ambient temperatures.

Other examples of where alloy N08367 has been used in previous nuclear power plants are shown below.

Tennessee Valley Authority (TVA):

Bellefont Nuclear	N08366	1984
Bellefont Nuclear	N08367	1985
Watts Bar Nuclear	N08367	1985
Browns Ferry #2	N08367	1988
Browns Ferry #3	N08367	1991

Long Island Lighting Co. (LIL[8]):

Shoreham Nuclear	N08366	1981

Taipower[9]:

Lungmen #4	N08367	2005

SPECIFICATION APPROVALS

UNS N08367 alloy is approved for use to 800°F (427°C) for ASME Section III (Nuclear) and ASME Section VIII Division I (unfired pressure vessel) applications. Alloy N08367 can be used for both safety related systems as well as other service water systems in nuclear power plants.

Use of N08367 alloy is allowed in the ASME Code for Pressure Piping, Sections B31.1 – Power Piping and B31.3 – Process Piping as UNS N08367.

The ASME maximum allowable design stress values for many N08367 alloy product forms are listed in Tables 2.

UNS N08367 wrought product is listed in the ASME Boiler and Pressure Vessel Code including Section II, Part D.

[8] LIL is a trademark of Long Island Lighting Company
[9] Taipower is a trademark of Taiwan Power Company

COST SAVINGS DUE TO LONGEVITY OF SERVICE WATER PIPING

The use of alloy N08367 greatly reduces the risk of corrosion and nearly eliminates the possibility for maintenance concerns. Alloy N08367 has been shown to improve service life and reduce maintenance costs as compared to 300 series stainless steels as well as carbon steel and duplex service water piping.

Stainless steel piping is subject to MIC and sudden failure due to cracking. If MIC attack is severe costly damages can occur during emergencies if the service water piping does not operate properly. Even if the damage is detected, the cost of replacing an existing system made from stainless steel or carbon steel is many time more costly than using a higher alloy such as N08367 in the initial design.

Stainless steel piping is subject to chloride stress corrosion cracking resulting in sudden failure. This type of failure is impossible to predict and can cause extremely costly damage during emergencies when the service water piping fails to operate properly.

Carbon steel piping is subject to general corrosion and biofouling of pump systems. Although the carbon steel piping is initially less expensive than using alloy N08367, the replacements costs if damage is detected are much more expensive than using alloy N08367 in the initial design.

Failures commonly occur underground where preventative maintenance and inspection is difficult or impossible. Complete underground service water piping replacement is extremely expensive and time consuming.

If a failure is not noticed until fire service water is needed, further damage can happen to the nuclear plant.

CONCLUSIONS

Super austenitic alloy N08367 provides a safe, reliable, corrosion resistant and cost effective option for service water piping in nuclear power plants. This is even more important for new nuclear plants being designed for 60 years, requiring more durable, corrosion resistant alloys

ACKNOWLEDGEMENTS

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TABLE 1: Chemistry of N08367, ASTM A240

	Minimum	Maximum
Nickel	23.50	25.50
Chromium	20.00	22.00
Molybdenum	6.00	7.00
Carbon	--	0.03
Nitrogen	0.18	0.25
Manganese	--	2.00
Silicon	--	1.00
Phosphorus	--	0.040
Sulfur	--	0.030
Copper	--	0.75
Iron	Remainder	

TABLE 2: ASME maximum allowable stress values for alloy N08367

For metal temperature not exceeding		Maximum Allowable Design Stress Values in tension, ksi (Mpa) DIMENSIONALLY STABLE Under Cited Conditions							
		< 3/16 inch thk sheet, strip, seamless		> 3/16 inch thk plate, bar, forgings		Welded Tube, Welded Pipe < 3/16 inch thk wall		Welded Pipe > 3/16 inch thick wall	
°F	**°C**	**45YS 100TS**	**(310) (717)**	**45YS 100TS**	**(310) (717)**	**45YS 100TS**	**(310) (717)**	**45YS 100TS**	**(310) (717)**
100	38	28.6	(197)	27.1	(187)	24.3	(167)	23.1	(159)
200	93	26.2	(181)	26.2	(181)	22.2	(153)	22.2	(153)
300	149	23.8	(164)	23.8	(164)	20.2	(139)	20.2	(139)
400	204	21	(151)	21	(151)	18.7	(129)	18.7	(129)
500	260	20.5	(141)	20.5	(141)	17.4	(120)	17.4	(120)
600	316	19.4	(134)	19.4	(134)	16.5	(114)	16.5	(114)
650	343	19	(131)	19	(131)	16.1	(111)	16.1	(111)
700	371	18.6	(128)	18.6	(128)	15.8	(109)	15.8	(109)
750	399	18.3	(126)	18.3	(126)	15.5	(107)	15.5	(107)
800	427	18	(124)	18	(124)	15.3	(105)	15.3	(105)

KEY: YS = Minimum yield strength 0.2% offset; TS = Minimum tensile strength

All product forms have a minimum 30% elongation in 2” or 4D.

Values shown are for comparison only. Always consult current editions of codes and standards for values for us in design.

Values are as published in 2001 edition of Code. Always consult current editions of codes and standards for values for us in design.

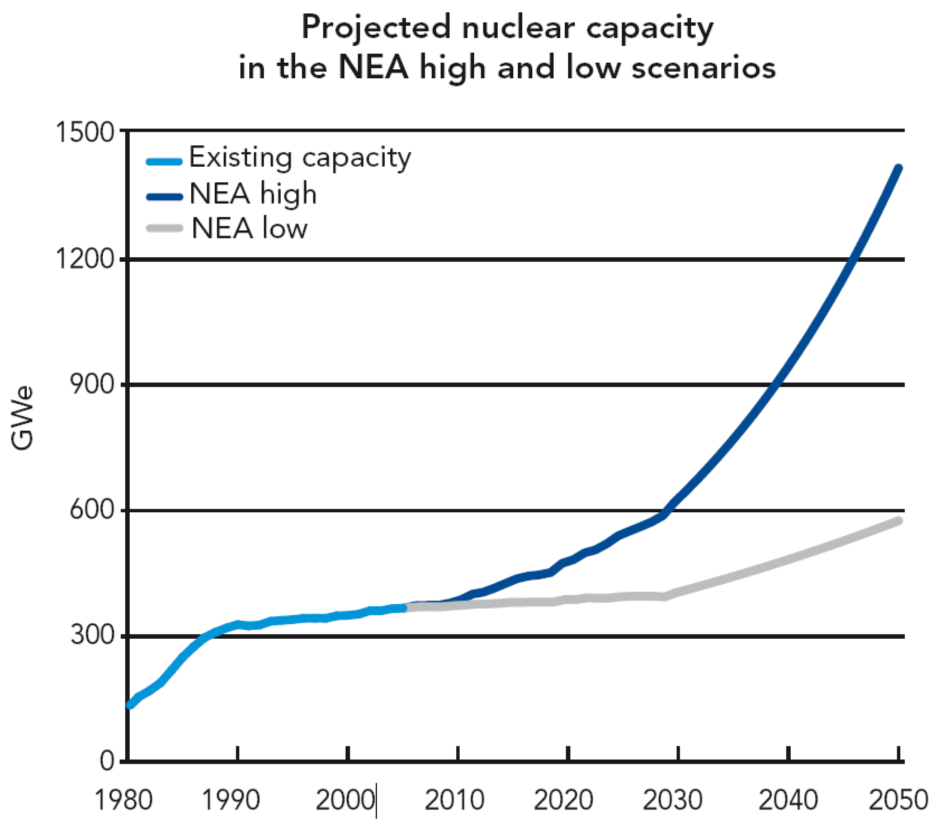
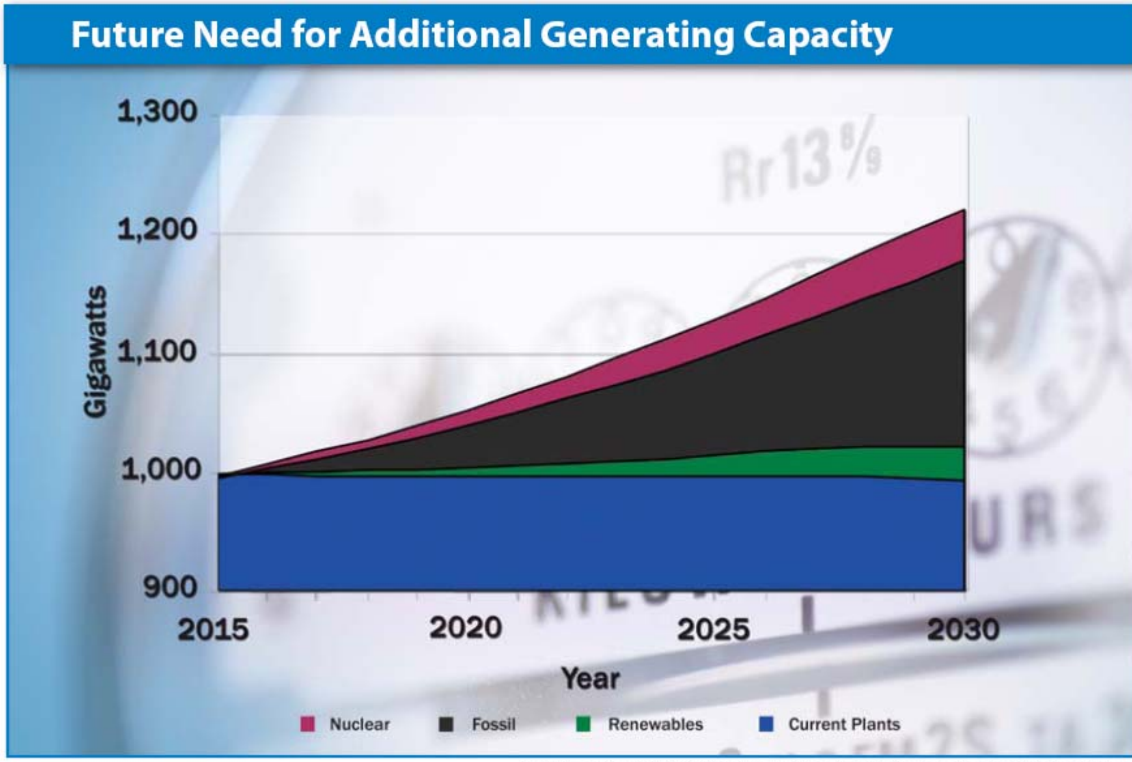


FIGURE 1: [5] – The Nuclear Energy Outlook 2008 expects the nuclear demand to at least double and possibly increase five times by year 2050.



Source: Energy Information Administration data and projections.

Assumptions:

- *Total capacity is from the EIA Annual Energy Outlook 2007 projection*
- *Nuclear capacity is assumed to be that necessary for nuclear to provide 20% of the mix in 2030*
- *Fossil capacity is reduced from the EIA Annual Energy Outlook 2007 projection by extra assumed nuclear capacity*
- *All unplanned capacity additions not broken out in EIA tables are assumed to be renewables*

FIGURE 2: [1] – The future need for additional electrical energy is predicted to grow at least 50 percent with nuclear power expanding to be a large portion of the supply.

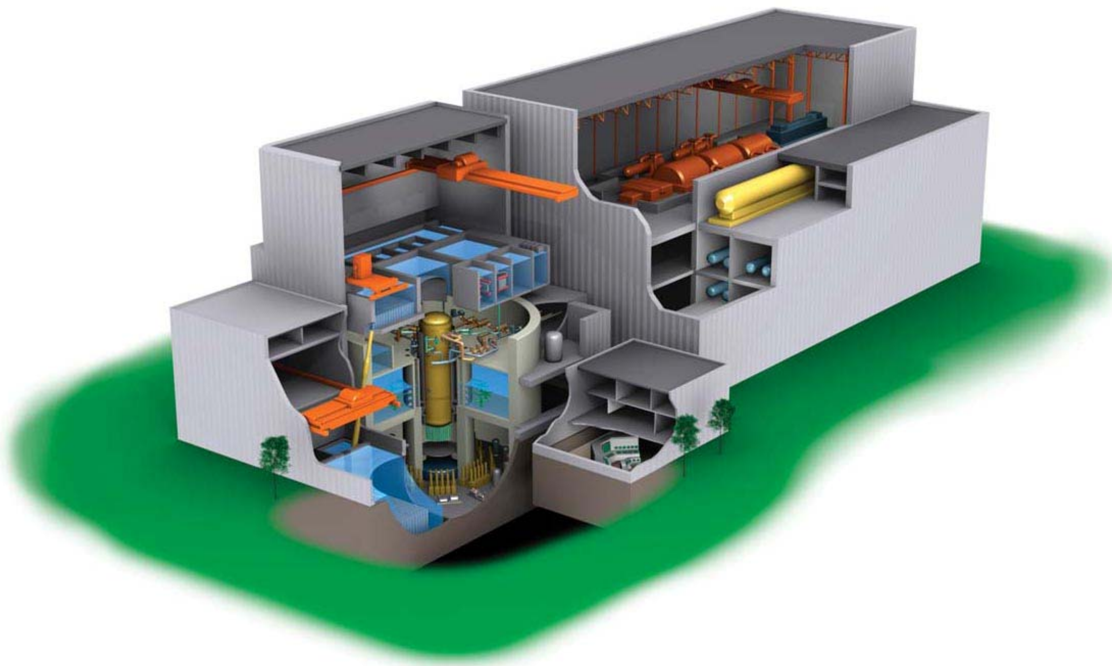


FIGURE 3: [1] - Cutaway view of an Advanced Boiling Water Reactor (ABWR), one of two reactor technologies in the NP2010 program.

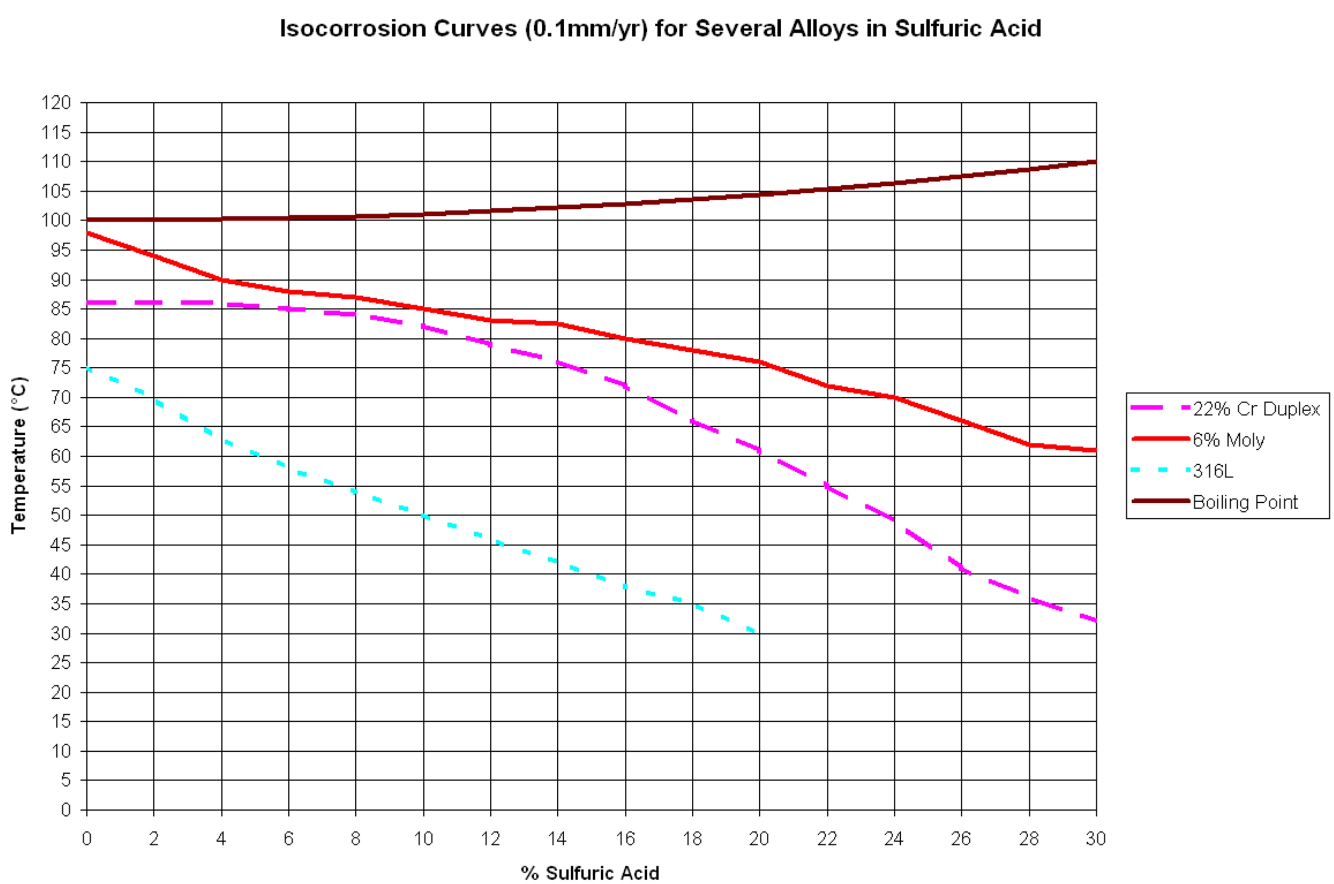


FIGURE 4:[3] – Isocorrosion curves for several alloys in sulfuric acid

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