STAINLESS STEELS FOR INDIAN NUCLEAR POWER REACTORS

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1.0 INTRODUCTION

Power has changed the lifestyle of man. It has become the most important infrastructure by contributing both directly and indirectly to economic development. Electricity is a basic necessity for the growth and prosperity of any country. The major options presently available for electricity generation are hydro, thermal and nuclear.

So far as hydel power is concerned though the identified potential is about 180,000 MW, only 20,000 MW is being generated. The long gestation period, resettlement of very large population, difficulties caused by complex geological condition, particularly in Himalayan region, have impeded the rate of exploitation of hydro electric potential.

The country's coal reserves are estimated about 186 billion tonnes and may last about 130 years. Nuclear power is one source, which is available at present and can generate electricity at costs comparable to coal fired stations in certain locations. There is no doubt that both thermal and hydel energy should continue to be developed in a major way to meet the growing electricity needs within the prevailing constraints. On the other hand it is also important to pursue nuclear power development in parallel so that it can meet the electricity demands at locations away from the coal fields. At present share of nuclear power generation in India is 2%.

Today, India is the only developing country that has demonstrated its capability to design, build, operate and maintain nuclear plants, manufacture all associated equipment and components and produce nuclear fuel and special materials. In fact, development of an indigenous nuclear power is one of the major achievements of independent India.

2.0 NUCLEAR POWER IS ENVIRONMENTALLY CLEAN

Many of the environmentally conscious countries in the world depend upon nuclear power significantly for their electricity generation. At present 17% of the world electricity is generated through nuclear sources. Nuclear source is clean, compact and concentrated. Clean for minimal impact on environment, compared to other commercial energy generating sources. There are no effects of acid rain due to emission of sulphur dioxide, carbon dioxide, nitrogen dioxide or global warming. The installation of nuclear power plant involves minimum land requirements and minimum displacement of local population. It also does not lead to submergence of precious land, forest, flora and fauna.

Compact - because it is available in forms of fuel bundles which, once loaded in the reactor core, provide energy for 1.5 to 2 years at a stretch before discharge. Concentrated - as one kg uranium gives energy equivalent 25,000 kg of coal.

But a nuclear plant does produce small amount of radiation. This radiation is not uncommon in our day to day life as it is present as natural background radiation. In the normal operation of a reactor, radiation dose to the general public or to the environment is a negligible fraction of the unavoidable natural radiation.

3.0 PHWR TYPE OF NUCLEAR POWER PLANTS

A nuclear power plant is much similar to a coal fired thermal plant except that the way heat is produced to raise steam. At the heart of a nuclear power plant is the fission reaction in the nuclear fuel, usually uranium, that takes place in the reactor core. The pressurised heavy water reactor (PHWR), uses natural uranium as fuel and heavy water as moderator and coolant. Typical PHWR cycle is shown in Figure-1.

4.0 STAINLESS STEELS FOR NUCLEAR REACTORS

The safe and reliable operation of a nuclear power plant depends on integrity of its critical equipment for full designed life. This demands high performance from materials of critical equipment in stressed and corrosive environment. In addition to this, materials are also subjected to neutron irradiation which leads to increase in nil ductility temperature (NDT). Stainless steels are employed extensively as structural material in nuclear power plants primarily due to favourable combination of mechanical properties, corrosion resistance and good impact properties.

Nuclear applications of stainless steel are nuclear reactor body, fuel cladding, nuclear material processing plants, reaction vessels and piping in chemical reprocessing plants handling irradiated fuel and structural materials and radioactive waste immobilisation plants to contain nuclear waste materials.

The passivity of stainless steel is the singular property responsible for its vast application in corrosive service environment. The passivity is due to oxide layer and is a function of alloying, heat treatment and environmental conditions. The breakdown of passive film results in pitting and crevice corrosion, intergranular corrosion and stress corrosion cracking.

These failures have to be viewed as serious concerns and special steps have to be taken to ensure that these are avoided in service.

The ferritic, austenitic and martensitic, are the fundamental types of stainless steels around which all types of compositions and grades have been developed, to suit particular application requirements.

For nuclear applications for the core components, the mechanical properties are usually specified, higher than for general engineering purposes. This is because neutron irradiation results in an increase in NDT. Therefore, to avoid in service failure, the alloy should have a higher toughness value at room temperature. Similarly, the yield strength of the material increases with neutron irradiation. Hence, the choice of alloy and microstructure is limited by a combination of increase in strength and fall of toughness. It is therefore, necessary to impose strict chemistry specification for nuclear alloys which are tighter than those for general engineering applications.

To meet the above specification requirements, the manufacturing route requires combination of arc melting, vacuum induction refining and electro slag refining or vacuum arc refining, etc., depending on the primary melt route.

In nuclear reactors various grades such as stainless steel types 304/304L, 316/316L, 403 and 17-4 PH are used extensively. Typical applications and requirements are given in Table-1 & 2.

4.1.0 Special quality requirement for nuclear stainless steels

There are three main reasons for specifying additional quality requirement for nuclear applications:

- Neutron irradiation can result in embattlement, enhanced creep and thereby make the material more susceptible to brittle fracture or affect the functioning of the component.
- Radiation causes formation of radioactive isotopes of elements in core components whose eventual corrosion or erosion and transport can cause much difficulty or even hinder the maintenance or in service inspection.
- Because of radioactivity involved, consequence of failure will be severe and hence quality of material has to be of highest standard to ensure structural integrity.

The stainless steel used in nuclear power industry should have specifications which take care of the above situations however all the above reasons may not be applicable to each and every situation.

4.1.1 Strict chemistry control

- By limiting certain elements like Cu, N, As, V, Sb, S problem of irradiation embrittlement can be minimised.
- By limiting elements like Co, B, to very low value (about .025% Max.) problem of induced radioactivity can be controlled.
- By keeping hydrogen levels low (less than 2 PP, M) the flaking in forgings can be avoided.
- By controlling elements like Cr, Mo, Si, etc., in austenitic stainless steels, delta ferrite can be kept very low to avoid transfer to brittle sigma phase during high temperature service. It also offers better hot workability.

Proper chemistry control of stainless steels is achieved by proper raw material selection, limiting the extent and selective grade of scrap for melting and utilising suitable refining processes.

4.1.2 Rigid examination and testing standards

Structural integrity is ensured by specifying rigid non-destructive examination standards. Volumetric examination (radiography / ultrasonic) or eddy current test (in case of thin tubes), one surface examination-either magnetic particle examination (for magnetic grade only) or liquid penetrant examination and finally hydrostatic testing are specified.

In all chemicals (including water for hydrotest) which come into contact with stainless steels, chlorides and other halogens are restricted to very low values (less than 25 ppm) to minimise possibility of stress corrosion cracking (SSC) due to leftover halides.

4.1.3 Macro/Micro cleanliness

The benefits of improving the macro or micro cleanliness by vacuum remelting/degassing or electro slag refining are manifolds. Some of them are, improved and consistent mechanical properties such as higher fatigue strength, higher ductility and higher impact strength, improved hot workability and better corrosion resistance. Better micro cleanliness or low inclusion content is specific to nuclear applications. Some inclusion with neutron exposure lead to helium concentration at grain boundaries causing embrittlement.

Macro etch test is useful in indicating the distribution and variation in size of non-metallic inclusions, location and extent of gross segregation, fabrication defects, etc.

4.2 Corrosion aspect for nuclear application

The choice of a particular grade of stainless steel depend on the type of reactor application and also on the environmental conditions. Stainless steel remain passive in high temperature and steady state corrosion rates are low. The thickness and tenacious nature of the oxide film formed on high alloy materials are sufficient for achieving isolating properties, so that galvanic effect in the corrosion processes are largely excluded.

4.2.1 Stress corrosion cracking

The essential limitation in- the use of austenitic stainless steels in high temperature water is due to their sensitivity to stress corrosion cracking. The sensitisation and the weld residual stress in the heat effected zone (HAZ) and the dissolved oxygen under operating conditions results in inducing intergranular stress corrosion cracking of 304. SS piping. In view of this special L and LN (nuclear) grade stainless steels have been developed for controlling the IGSCC problem.

4.3 Handling of stainless steel components

Critical components are fabricated and assembled in clean room conditions, where exclusively staillless steel is handled in dust and chloride free environment. The humidity is also controlled to avoid sweating of the personnel working in the fabrication shop. Sweating contains high levels of detrimental chlorides.

.The common practice of using all tools and accessories separately for stainless steels for avoiding contamination is strictly implemented.

All chemicals and relevant materials that come into contact are checked for chloride presence. These include penetrant, developer, cleaner, insulation materials, paint and water used both for cleaning and hydrotest.

4.4 Cleaning

Stainless steel products have to undergo cleaning processes during the final stages of manufacture. Cleaning may consists of pickling, polishing and finishing operations. Great attention must be paid to the cleaning process of stainless steel products to improve their performance in service.

Pickling of stainless steel is a very common practice. The products after hot or cold working and heat treatment are pickled and passivated in accordance with the approved procedure.

5.0 INDIA'S NUCLEAR POWER PROGRAMME

India's nuclear power programme is envisaged in three stages:

Stage-I :	envisages construction of natural uranium, heavy water moderated and cooled pressurised water reactors. Spent fuel from these reactors is reprocessed to obtain plutonium.
Stage-II :	envisages construction of fast breeder reactors (FBRs) fuelled by Plutonium produced in stage I. These reactors will also breed uranium-233 from thorium.
Stage-III :	would comprise power reactors using uranium-233/thorium as fuel.

Nuclear power was ushered in India in 1969 with the Tarapur Atomic Power Station (TAPS), comprising two boiling water reactors (BWRs). The station was set up on a turnkey basis by General Electric Company, USA. Indian participation in setting up of these units extended to site selection, tender preparation and evaluation, design reviews, operation and maintenance and construction services in certain service systems and local services in civil construction work.

Though Indian nuclear power programme is essentially based on PHWRs using natural uranium as fuel and heavy water as moderator and coolant, the Tarapur station was set up essentially to prove the technical viability of operating such units, which were, at that time considered largest in the Indian grids.

This also provided opportunity to gain valuable experience in operation and maintenance of nuclear power stations. This station has seen a safe operating record of over 28 years providing the much-needed electricity to the Western Region.

The accumulated experience with 220 MWe PHWR units and the progressively increasing size of the electrical grids led to the next logical step of undertaking the design work for larger 500 MWe PHWR units. These designs have now been finalised. Engineering details of several components have been finalised and some of the selected long delivery and critical components have been manufactured. Recently excavation of the ground at Tarapur, Maharashtra indicating start of site construction activities has been carried out.

Two reactors of 1000 MWe each are proposed at Kundankulam in Tamil Nadu. These reactors are of pressurised water design in which enriched uranium (U-235 greater than 0.7%) fuel and light water as moderator are used. For these reactors, statutory clearances have been obtained and land acquisition has been completed. Work on detailed project report has been taken up.

Present status of Indian Nuclear Power Programme covering Stage-I is given in Table 3.

Further, to accelerate growth of nuclear power; it is contemplated to build a few light water reactor based plants with foreign collaboration. The immediate objective is to achieve 20,000 MW of generation capacity by the year 2020.

6. OTHER NICKEL ALLOYS

In addition to stainless steels, other nickel-based alloys used in nuclear reactor are

- Monel-400
- Incoloy-800
- Inconel-600, 600T, 690TT
- Cupro-Nickel

- Nickel for soft electroplating for sealing surfaces
- Nickel tubes in shock absorber assemblies.

7. CONCLUSION

The Indian stainless steel industry counts among the fastest growing in the world. A commendable progress has been made in the manufacture of stainless steel to a higher standard of quality. There is still a need to augment manufacturing facility for thicker sections of plates, tubes, rounds etc. to meet the nuclear grade requirement for specific applications in nuclear industry. There is a need as well as scope to invest in research and development, to refine the manufacturing processes to achieve higher demands of quality. Stringent quality control methods have to be followed to meet the desired quality levels during all stages of manufacturing. Efforts must be made to achieve self-reliance in the production of stainless steel to meet the challenges and demands of the industry.

Table 1: Typical application of some stainless steels in reactors.

Grade	Type	Compowents
304L	Austenitic	Calandria, dump, tank, end shields, piping material for moderator system, fuelling machine, linings of reactor vault, spent fuel, etc.
316/316L	Austenitic	Heavy water pumps, fuelling machines, fast breeder reactor vessel, sodium pumps, piping
403 (modified)	Martensitic	End fittings, dump tank support legs.
17-4 PH	Precipitation Hardened	Seal discs, ball screws, fuelling machine pressure housing, fuelling machine head and other reactivity mechanism components.
PH 13-8 Mo	Precipitation Hardened	Ram head assemblies of fuelling machine heads and seal discs (500 MWe)

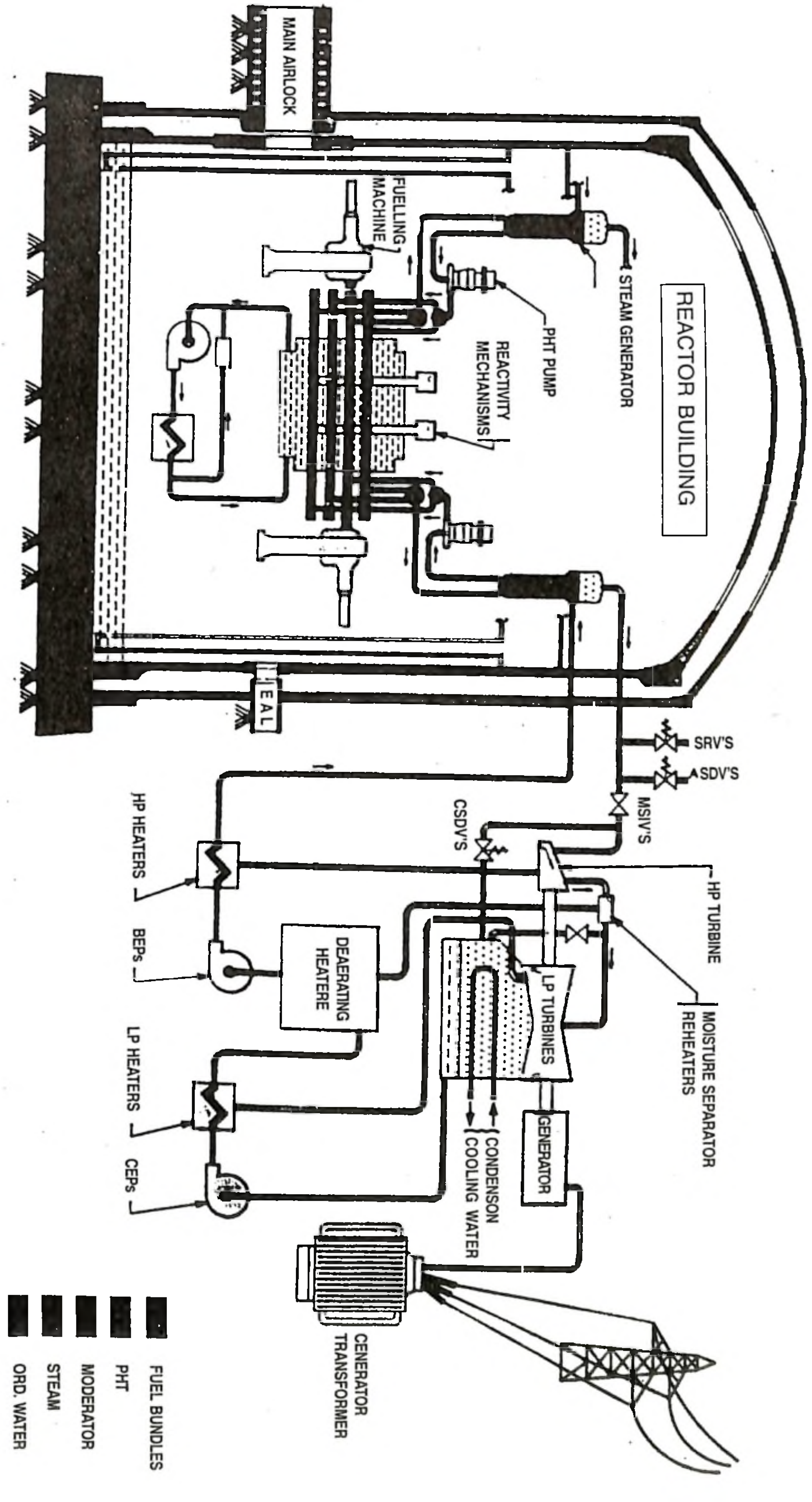
Table 2: Requirement of stainless steel for PHWR's .

(FOR ONE REACTOR)

Types of steel	Form	ASTM/ASME Specification	Tonnes (220 MWe)	Tonnes (500 MWe)
Austenitic	Plate	A 240 type 304L	280	700
Austenitic	Pipe	A 312 type 304L, 316L	270	300
Austenitic	Forgings	A 182 F 304L, 316L	40	60
Austenitic	Bars	A 479 type 304, 304 L	40	5
Austenitic	Rectangular tube section	304L		50
Martensitic	Tubes	A 268 type 410	5	50
Martensitic	Bars and billets	A 479 410, 403	540	800
Precipitation Hardened	Forgings/Bars	A 564 type 630 (17-4 PH) A564 Gr XM-13 (PH 13-8 Mo)	80	210

Table 3: Present status of Indian Nuclear Power Programme (Stage-I).

Unit	Location	Type	Rated Capacity (MWe)	First Criticality	Commercial Operation	Remarks
TAPS-1	Tarapur (Maharashtra)	BWR	160	1.2.69	28.10-69	
TAPS-2	Tarapur (Maharashtra)	BWR	160	28-2-69	28-10-69	
RAPS-I	Rawatbhata (Rajasthan)	PHWR	200	11-8-72	16-12-73	
RAPS-2	Rawatbhata (Rajasthan)	PHWR	200	8-10-80	1-4-81	
MAPS-I (Tamil Nadu)	Kalpakkam	PHWR	220	2-7-83	27-1-84	Presently being operated at 175 MWe consequent to failure of moderator inlet manifolds inside calandria
MAPS-2	Kalpakkam (Tamil Nadu)	PHWR	220	12-8-85	21-1-86	
NAPS-I	Narora (U.P.)	PHWR	220	12-3-89	1-1-91	
NAPS-2	Narora (U.P.)	PHWR	220	24-10-91	1-7-92	
KAPS-1	Kakrapar (Gujarat)	PHWR	220	3-9-92	6-5-93	
KAPS-2	Kakrapar (Gujarat)	PHWR	220	1-1-95	1-9-95	
KAIGA-1	Kaiga (Karnataka)	PHWR	220	Expected Criticality Oct. 99.		
KAIGA-2	Kaiga (Karnataka)	PHWR	220	Expected Criticality April 99.		
RAPP-3	Rawatbhara (Rajasthan)	PHWR	220	Expected Criticality July 99.		
RAPP-4	Rawatbhara (Rajasthan)	PHWR	220	Expected Criticality Dec. 99.		
TAPP-3	Tarapur (Maharashtra)	PHWR	500			
TAPP-4	Tarapur (Maharashtra)	PHWR	500			
Kudankulam-1	(Tamil Nadu)	PWR	1000	Detailed Project report being prepared		
Kudankulam-2	(Tamil Nadu)	PWR	1000	Detailed Project report being prepared		



SCHEMATIC DIAGRAM OF INDIAN PHWR
(COASTAL SITE)