A.2 Materials of Construction

As detailed in Tables A.1-A.4, which are excerpted from the appropriate sections in Appendix B, there is a large variety of metallic materials used in the fabrication of PWR and BWR pressure boundary and internal components that include the following combinations:

1. *Reactor Coolant Piping and Fittings* – carbon steel, low-alloy steel, cast and wrought stainless steels and various weld materials depending on the parent material used.
2. *Reactor Pressure Vessel* and *PWR Pressurizer Vessel* - low-alloy steel, stainless steel cladding, wrought nickel-base penetrations and various weld materials.
3. *Reactor Internals* – cast and wrought austenitic stainless steels, nickel-base alloys, and their associated weld metals.
4. *PWR Steam Generator* – low alloy and carbon steels, stainless steel cladding, nickel-base alloys, and various weld materials.
5. *Pumps* – cast and wrought austenitic stainless steels for pressure boundary materials; various high alloy steels for bolting and austenitic or martensitic stainless steels for pump shafts and other internal components.

Table A.1 Compositions of Carbon & Low Alloy Steels Used in LWR Pressure Vessels and Piping (wt. %)

	A533-B	A508-2	A508-3	A333-6	A516
Carbon (max)	0.25	0.27	0.25	0.30	0.28
Manganese	1.15 – 1.50	0.5 – 1.00	1.20 – 1.50	0.29- 1.06	0.60 – 1.20
Phosphorus (max)	0.035	0.025	0.025	0.025	0.035
Sulfur (max)	0.035	0.025	0.025	0.025	0.035
Silicon	0.15 – 0.40	0.15 – 0.40	0.15 – 0.40	≤0.10	0.15 – 0.40
Nickel	0.40 – 0.70	0.50 – 1.00	0.40 – 1.00		
Chromium		0.25 – 0.45	≤0.25		
Molybdenum	0.45 – 0.60	0.55 – 0.70	0.45 – 0.60		
Vanadium		≤0.05	≤0.05		

Table A. 2 Compositions of Some Stainless Steels Commonly Used in LWRs (wt. %)

	Type 304L	Type 316	Type 321	Type 347	Type 308L	Type 309L	A-286	17-4PH
Carbon (max)	0.03	0.08	0.08	0.08	0.03	0.03	0.08	0.07
Manganese(max)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.00
Silicon (max)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00
Chromium	18-20	16-18	17-19	17-19	19-21	22-24	12-15	15-17.5
Nickel	8-12	10-14	9-12	9-13	10-12	12-15	24-27	3.0-5.0
Molybdenum		2.0-3.0					1.00-1.50	
Phosphorus (max)	0.045	0.045	0.045	0.045	0.045	0.045	0.040	0.040
Sulfur (max)	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Other elements			Ti >5C	Nb+Ta >10C			Ti 1.55-2.00 Al ≤0.35 V 0.10-0.50	Cu 3.0-5.0 Nb+Ta 0.15-0.45

Table A. 3 Compositions of Cast Stainless Steels used in LWRs (wt. %)

	CF-3	CF-3A	CF-8	CF-8A	CF-8M
Carbon (max)	0.03	0.03	0.08	0.08	0.08
Manganese (max)	1.50	1.50	1.50	1.50	1.50
Silicon (max)	2.00	2.00	2.00	2.00	1.50
Sulfur (max)	0.040	0.040	0.040	0.040	0.040
Phosphorus (max)	0.040	0.040	0.040	0.040	0.040
Chromium	17.0-21.0	17.0-21.0	18.0-21.0	18.0-21.0	18.0-21.0
Nickel	8.0-12.0	8.0-12.0	8.0-11.0	8.0-11.0	9.0-12.0
Molybdenum (max)	0.50	0.50	0.50	0.50	2.0-3.0

All of the above materials are potentially susceptible to one or more degradation modes, depending upon the combinations of material and service conditions. Some of these combinations for PWRs are indicated in Table A.5 as an example of the range of degradation modes and how their emergence changes between one system and another. For example, alloys, which may potentially degrade by a given mode in a given system, are shaded in Table A.5 (with no judgment being made as to the extent of the degradation). The environmental conditions shown in the Table have been chosen to represent the range of chemistry and temperature conditions in various PWR systems (e.g., Reactor Coolant System, both primary and secondary; Emergency Core Coolant System (ECCS); Service Water; etc). Although stress corrosion (SCC) and fatigue (FAT) are possible for the majority of the chosen environment/material combinations, other degradation modes will change with different system conditions. For instance, microbiologically-induced-corrosion (MIC) will not be an issue in the higher temperature borated RCS, since the microbes cannot survive under these conditions, but MIC may be an issue in the lower temperature systems, such as parts of ECCS, and especially in those reactor systems that are not borated, such as the component coolant and service water systems. Ranges in temperature are shown in some of the system examples, and this will give rise to a range in degradation susceptibilities within that system since most of the degradation modes are temperature activated to different degrees. It is the objective of the PMDA project to assess the extent to which these susceptibilities may vary due to temperature, material condition, etc. for each component within the various subsystems (and to assess whether there is sufficient knowledge to predict and mitigate this degradation). It should also be noted in Table A.5 that many of the alloy/degradation mode combinations are shown blank; indicating that although there may be a possibility of degradation, its likelihood of occurrence is small. The rationale for such judgments is either the fact that that particular combination (marked with an X) does not occur (e.g., there are no Alloy 82/182 welds in the highly irradiated core region, so irradiation induced creep is unlikely), or there are mechanistic reasons to judge that the likelihood of degradation is low; this latter aspect is covered in Section A.4 of this Appendix.

Table A. 4 Compositions of Nickel base alloys used in LWRs (wt. %)

	Alloy 600	Alloy 182	Alloy 82	Alloy 690	Alloy 152	Alloy 52	Alloy 800	Alloy X750	Alloy 718
Nickel	>72.0	Bal.	Bal.	>58.0	Bal.	Bal.	30-35	>70.0	50-55
Chromium	14-17	13-17	18-22	28-31	28-31.5	28-31.5	19-23	14-17	17-21
Iron	6-10	≤10.0	≤3.00	7-11	8-12	8-12	>39.5	5-9	Bal.
Titanium		≤1.0	≤0.75		≤0.50	≤1.0	0.15-0.60	2.25-2.75	0.65-1.15
Aluminum						≤1.10	0.15-0.60	0.4-1.0	0.2-0.8
Niobium plus Tantalum		1.0-2.5	2.0-3.0		1.2-2.2	≤0.10		0.7-1.2	4.75-5.50
Molybdenum					≤0.50	≤0.05			2.8-3.3
Carbon (max)	0.05	0.10	0.10	0.04	0.045	0.040	0.10	0.08	0.08
Manganese	≤1.0	5.0-9.5	2.5-3.5	≤0.50	≤5.0	≤1.0	≤1.50	≤1.0	≤0.35
Sulfur	≤0.015	≤0.015	≤0.015	≤0.015	≤0.008	≤0.008	≤0.015	≤0.010	≤0.010
Phosphorus		≤0.030	≤0.030		≤0.020	≤0.020			
Silicon	≤0.5	≤1.0	≤0.50	≤0.50	≤0.65	≤0.50	≤1.0	≤0.5	≤0.35
Copper	≤0.5	≤0.50	≤0.50	≤0.5	≤0.50	≤0.30	≤0.75	≤0.5	≤0.30
Cobalt	≤0.10	≤0.12	≤0.10	≤0.10	≤0.020	≤0.020			

Table A. 5 Expected Alloy/Degradation Mode Combinations for PWRs (GC=General Corrosion; BAC=Boric Acid Corrosion; FAC= Flow Accelerated Corrosion; CREV= Crevice Corrosion; PIT=Pitting; GALV=Galvanic Attack; SCC=Stress Corrosion Cracking; MIC= Microbiologically-Induced Corrosion; FAT= Fatigue)

	"General Corrosion"			"Localized Corrosion"					"Mechanical"			
Alloy System	GC	BAC	FAC	CREV	PIT	GALV	SCC	MIC	FAT	Therm. Emb.	Irrad Emb	Irrad Creep
	Reactor Coolant System, 550-650 F, PWR Primary and Secondary Water											
Low Alloy & Carbon Steel												
Wrought Stainless Steel, 304/316												
Stainless Steel Welds 308/309												
Cast Stainless Steel CF8/CF8M											X	X
Alloy 600 Nozzles, Safe-ends, SGTubes											X	X
Alloy 82/182 Welds											X	X
		Main Feedwater, 250-450F, Demin Water, pH 9-10										
Carbon Steel Piping												
Alloy 690 Forging												
			Main Steam Line, 445-530F , Steam									
Low Alloy & Carbon Steel												
			CVCS, 115-290F, PWR Primary Water									
Low Alloy Steel Bolts (assume leakage)												
Wrought Stainless Steel, 304/316												
Stainless Steel Welds 308/309												
Cast Stainless Steel CF8/CF8M												
	Emergency Core Cooling System, 100-150 F, Borated Demin Water											
Wrought Stainless Steel, 304/316												
Stainless Steel Welds 308/309												
Cast Stainless Steel CF8/CF8M												
		Component Cooling Water,105-130F, Treated Water										
Low Alloy & Carbon-Steel Piping / Fittings												
			Service Water System, 100F, Pond Water									
Low Alloy & Carbon-Steel Piping / Fittings												
Wrought Stainless Steel, 304/316 HX tubing												
Stainless Steel Welds 308/309												
Copper base alloys HX tubing												