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The elemental composition of the structural materials of nuclear reactor facilities is used as one of the important parameters in activation calculations that are evaluated when formulating decommissioning plans. Regarding the elemental composition of aluminum alloys and other materials used as structural materials for test and research reactors, sufficient data is not available regarding elements other than the major elements. For this reason, samples were collected from aluminum alloy, beryllium, hafnium, and other materials that have been used as the main structural materials of JMTR (Japan Materials Testing Reactor), and their elemental compositions were analyzed. This report summarizes the elemental composition data of 78 elements obtained in FY2023.

Keywords: Elemental Composition, Aluminum, Beryllium, Hafnium, Lead, Stainless Steel, JMTR

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＋1 Radioactive Wastes Disposal Center, Decommissioning and Waste Management Domain

＋2 Nuclear Backend Technology Development Department, Nuclear Fuel Cycle Engineering Laboratories

JMTR の主要構造材の元素組成分析

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原子炉施設の構造材の元素組成は、廃止措置計画の策定などの際に評価を行う放射化計算において、重要なパラメータの一つとして使用されている。このうち、試験研究炉の構造材として使用されているアルミニウム合金などの元素組成については、主要成分以外の元素については十分なデータが得られていない。このことから、材料試験炉「JMTR」の主要な構造材として使用されてきたアルミニウム合金、ベリリウム、ハフニウムなどから試料を採取し、元素組成の分析を実施した。本報告書は、令和 5 年度に取得した 78 元素の元素組成データについてまとめたものである。

本報告書は、株式会社コベルコ科研が日本原子力研究開発機構との契約により実施した業務成果に関するものである。
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1. Introduction

The elemental composition of the structural materials of nuclear reactor facilities is used as one of the important parameters in activation calculations that are evaluated when formulating decommissioning plans.

Regarding the elemental composition of structural materials widely used in nuclear reactor facilities such as stainless steel, there is data published by the Nuclear Regulatory Commission (NRC)[1)2)] in the United States and analysis data of structural materials by the Fugen Nuclear Power Plant[3)4)]. It is widely used for activation calculations[5)6)].

On the other hand, the mill test certificate for structural materials are available for the elemental composition of aluminum alloys and other materials used as structural materials for test and research reactors, but only the major elements are listed. Therefore, sufficient data is not available regarding elements other than the major elements.

For this reason, samples were collected from aluminum alloy, beryllium, hafnium, and other materials that have been used as the main structural materials of JMTR (Japan Materials Testing Reactor), and their elemental compositions were analyzed. This report summarizes the elemental composition data of 78 elements obtained in FY2023.

2. Sampling Target

The sampling targets were aluminum alloy, beryllium, hafnium, lead, and stainless steel, which have been used as the main structural materials of JMTR.

An overview of the sampling targets is shown in **Table 1**, and details are shown below. In the elemental composition analysis, a part of the structural material is collected by mechanical cutting, etc., and the sample is adjusted to be suitable for each analysis method and used as the analysis sample.

(1) Aluminum Alloy

Among the aluminum alloys, samples of A5052, A6061, and A6063 were collected from JMTR core elements such as aluminum reflectors and aluminum plugs that were not used and stored as spare parts. The manufacturing history of the aluminum reflector and aluminum plug is shown in **Table 2**, the outline diagram is shown in **Fig. 1** to **3**, the external appearance is shown in **Photo 1**, and the chemical components listed in the mill test certificate are shown in **Table 3**.

Among the aluminum alloys, sample of A1050 was produced as an irradiation sample for the hydraulic rabbit irradiation device, and was collected from an unused and stored specimen. The outline diagram is shown in **Fig. 4**, the external appearance is shown in **Photo 2**, and the chemical components listed in the mill test certificate are shown in **Table 3**.

(2) Beryllium

Beryllium samples were collected from beryllium plugs that were manufactured as plugs for the beryllium frame, which are core elements of JMTR, that were not used and were stored as spare parts. The manufacturing history of the beryllium frame (beryllium plugs) is shown in **Table 4**, the outline diagram is shown in **Fig. 5**, the external appearance is shown in **Photo 3**, and the chemical components listed in the mill test certificate are shown in **Table 5**.

(3) Hafnium

Hafnium samples were collected from control rods that were manufactured as JMTR core elements, which were stored as spare parts, and from welding test pieces produced during control rod manufacturing. The manufacturing history of the hafnium is shown in **Table 6**, the outline diagram is shown in **Fig. 6**, the external appearance is shown in **Photo 4**, and the chemical components listed in the mill test certificate are shown in **Table 7**.

(4) Lead

The ex-core test equipment at the OGL-1 irradiation facility uses lead as a shielding material, and a lead sample was collected from the dismantled equipment. The external appearance is shown in **Photo 5**.

(5) Stainless Steel

Samples of stainless steel (SUS304 and SUS630) were collected from one component of the control rod. The manufacturing history and outline diagram are the same as (3) above. The external appearance is shown in **Photo 6**, and the chemical components listed in the mill test certificate are shown in **Table 8**.

3. Analytical Method

(1) Target Elements of Analysis

The target elements of analysis were selected for approximately 78 naturally occurring elements, excluding noble gases. These elements were set to include the parent elements of the 33 main nuclides for which clearance levels[7] have been set, the elements targeted for analysis by NUREG[1)2)], and the elements analyzed in structural materials of the Fugen Nuclear Power Plant[3]. The target elements of analysis are shown in **Table 9**.

(2) Analytical Method

The analysis method used was GD-MS (Glow Discharge Mass Spectrometer)[8], and gas analysis and chemical analysis were used for some elements. The analysis method used are shown in **Table 9** and the main specifications of the analyzer used are shown in **Table 10**.

GD-MS is a method for mass spectrometry by ionizing elements sputtered from a sample by glow discharge, that is used to analyze structural materials of the Fugen Nuclear Power Plant[3] as well as various metals[9)10)11)]. The analytical value is determined from the IBR (Ion Beam Ratio) and RSF (Relative Sensitivity Factors) of the main component element and target element and represents a semi-quantitative value.

(3) Preparation of Analysis Sample

Samples used for GD-MS and gas analysis were adjusted to samples for measurement using a high-speed precision cutting machine, hand saw, etc. Samples used for chemical analysis was collected from chips produced by cutting with an end mill, drill, etc. Furthermore, the surface of samples used for GD-MS was dissolved by heating with dilute hydrochloric acid, washed with pure water, and then polished to obtain a measurement sample.

4. Results

(1) Aluminum Alloy

The results of elemental composition analysis of the aluminum alloy are shown in **Table 11** and a comparison of the analysis results of the main component elements and the mill sheet values are shown in **Fig. 7**.

Out of a total of 78 elements analyzed, detection values for 58 elements and lower detection limits for 19 elements were obtained. The analysis results and mill sheet values generally agreed. In addition, the coefficient variation (SD/Avg) by the average value (Avg) and standard deviation (SD) of the analysis results obtained this time varied widely, ranging from 5 to 150%. In particular, the variation exceeded 100% for Be, F, Na, Mg, Cl, Cr, Cu, Se, Br, Sr, Ru, Pd, Sb, Gd, and Dy. This seems to be due to the difference in the materials of A5052, A6061, A6063, and A1050.

A plot of all elemental composition data including analytical data from other facilities[3)4)5)12)] are shown in **Fig. 8**. A comparison with analytical data from other facilities showed good agreement for A6061 at the Rikkyo University Reactor and JMTR, especially in Fe, Co, Cu, and U, but differences were seen in many elements at the Fugen Nuclear Power Plant. Since the material of the Fugen Nuclear Power Plant is unknown, so it may be a different material from the A6000 series, A5000 series, and A1000 series analyzed this time.

(2) Beryllium

The results of elemental composition analysis of the beryllium are shown in **Table 12**, a comparison of the analysis results of the main component elements and the mill sheet values are shown in **Fig. 9**, and a plot of all elemental composition data are shown in **Fig. 10**.

Of the 78 elements analyzed, detection values for 48 elements and lower detection limits for 29 elements were obtained. In comparing the analysis results and mill sheet values, the analysis results showed lower values for some elements, but when other mill sheet values were included, they were within that range and generally matched. In addition, the coefficient variation (SD/Avg) by the average value (Avg) and standard deviation (SD) of the analysis results obtained this time varied widely, ranging from 4 to 156%. In particular, the variation exceeded 100% for Li, K, Br, Sn, Au, Bi, and Th. This is considered to be due to differences between manufacturers of the material as shown in **Table 4**.

(3) Hafnium

The results of elemental composition analysis of the hafnium are shown in **Table 13**, a comparison of the analysis results of the main component elements and the mill sheet values are shown in **Fig. 11**, and a plot of all elemental composition data are shown in **Fig. 12**.

Of the 78 elements analyzed, detection values for 29 elements and lower detection limits for 48 elements were obtained. The analysis results and mill sheet values generally agreed. Although the analysis results for some elements are lower, the mill sheet value is lower detection limits and this is considered to be a difference in accuracy depending on the analysis method. In addition, the coefficient variation (SD/Avg) by the average value (Avg) and standard deviation (SD) of the analysis results obtained this time varied widely, ranging from 19 to 169%. In particular, the variation exceeded 100% for P, Ti, V, Cr, Mn, Fe, Co, As, and Mo. This is thought to be due to differences in manufacturing lots, as one (Sample No.9) of the three analysis results has a different value from the other two (Sample No.8, Sample No.10).

(4) Lead

The results of elemental composition analysis of the lead are shown in **Table 14** and a plot of all elemental composition data are shown in **Fig. 13**. Of the 78 elements analyzed, detection values for 19 elements and lower detection limits for 58 elements were obtained.

(5) Stainless Steel

The results of elemental composition analysis of the stainless steel are shown in **Table 14** and a comparison of the analysis results of the main component elements and the mill sheet values are shown in **Fig. 14**. Of the 78 elements analyzed, detection values for 49 elements and lower detection limits for 29 elements were obtained. The analysis results and mill sheet values generally agreed.

A plot of all elemental composition data including analytical data from other facilities[1)2)3)4)] are shown in **Fig. 15**. The elemental composition data for SUS304 generally agreed with data of the Fugen Nuclear Power Plant.

5. Conclusions

In this report, samples were collected from the main structural materials of JMTR, and their elemental compositions data used in activation calculations of structural materials of nuclear reactor facilities were analyzed. The detection values and lower detection limits for the 78 elements analyzed were obtained. In the future, the elemental composition data are continued to obtain through sample collection and analysis of other structural materials.

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Table 1 Overview of sampling targets

No.	Material	Structural material name	Shape (mm) Quantity	Remarks
1	Aluminum Alloy (A6063)	Aluminum reflector 1 hole C type 42 ϕ FR (C007)	□77×L1188 1 rod	**Fig. 1** **Photo 1**
2	Aluminum Alloy (A5052)	Aluminum plug 1 hole E type 67 ϕ FR (E005)	ϕ 65×L1039 1 rod	**Fig. 2** **Photo 1**
3	Aluminum Alloy (A6061)	Aluminum plug 1 hole F type 62 ϕ FR (F04F)	ϕ 60×L1039 1 rod	**Fig. 3** **Photo 1**
4	Aluminum Alloy (A1050)	Hydraulic rabbit (RM-4897)	ϕ 32×L150 1 piece	**Fig. 4** **Photo 2**
5	Beryllium	Beryllium plug ϕ 38Be for Be-frame (No.21)	ϕ 36×L820 1 rod	**Fig. 5** **Photo 3**
6	Beryllium	Beryllium plug ϕ 38Be for Be-frame (No.52)	ϕ 36×L820 1 rod	**Fig. 5** **Photo 3**
7	Beryllium	Beryllium plug ϕ 42Be for Be-frame (No.79)	ϕ 40×L820 1 rod	**Fig. 5** **Photo 3**
8	Hafnium	Control rod (Hf-24)	□63×L830 1 rod	**Fig. 6** **Photo 4**
9	Hafnium	Control rod (Hf-27)	□63×L830 1 rod	**Fig. 6** **Photo 4**
10	Hafnium	Preliminary welding test piece of control rod	□65×L150 1 piece	**Photo 4**
11	Lead	Lead shielding block	150×150×40 1 piece	**Photo 5**
12	Stainless Steel (SUS304)	(Same as No.9)	(Same as No.9)	**Photo 6**
13	Stainless Steel (SUS630)	(Same as No.9)	(Same as No.9)	**Photo 6**

Table 2　Manufacturing history of the aluminum reflector and aluminum plug

No.	Structural material name	Quantity	Main material	Manufacturing year	Manufacturer
A63-1	1 hole 42 φ FR (A001F-A010F)	11	A6063	S42 (1967)	Sumitomo Light Metal Industries, Ltd.
	1 hole 42 φ FR (A011-A130)	120			
	4 hole 32 φ FR (A001F-A005F)	5			
	4 hole 32 φ RR (A006-A030)	25			
	1 hole W type 64 φ RR (W001-W020)	20			
A63-2	1 hole C type 42 φ FR (C001-C007)※1	7		S45 (1970)	
A63-3	1 hole D type 38 φ FR (D001-D004)	4			
A52-1	1 hole E type 67 φ FR (E001-E003)	3	A5052	S51 (1976)	Kobe Steel, Ltd.
	1 hole F type 62 φ FR (F001)	1			
A52-2	4 hole 32 φ FR (A006F-A009F)	4		S52 (1977)	
A52-3	1 hole E type 67 φ FR (E004-E005)※2	2		S53 (1978)	Sumitomo Light Metal Industries, Ltd. Kobe Steel, Ltd.
	1 hole F type 62 φ FR (F002-F003)	2			
A61-1	1 hole F type 62 φ FR (F01F-F02F)	2	A6061	S54 (1979)	Kobe Steel, Ltd.
A61-2	1 hole F type 62 φ FR (F03F-F04F)※3	2		H2 (1990)	
A61-3	1 hole F type 62 φ FR (F05F-F08F)	4		H13 (2001)	
	1 hole E type 67 φ FR (E006)	1			
A61-4	1 hole E type 67 φ FR (E007)	1		H16 (2004)	
A61-5	1 hole E type 67 φ FR (E008-E009)	2		H21 (2009)	Nikkeikin Aluminium Core Technology Company, Ltd.

※1：Sample No.1

※2：Sample No.2

※3：Sample No.3

Table 3 Chemical components listed in the mill test certificate of aluminum alloy (1/2)

<A6063>Unit : %

Elements	Standard value		A63-1									A63-2			A63-3	
	Lower	Upper	—									Reflector	Plug	Lower plug	Reflector	Plug
Mg	0.45	0.9	0.57	0.63	0.6	0.64	0.64	0.6	0.6	0.62	0.62	0.58	0.55	0.59	0.55	0.55
Al	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Si	0.2	0.6	0.36	0.41	0.39	0.38	0.38	0.39	0.39	0.4	0.4	0.42	0.42	0.43	0.42	0.42
Ti	—	0.1	—	—	—	—	—	—	—	—	—	<0.01	—	—	<0.01	—
Cr	—	0.1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mn	—	0.1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Fe	—	0.35	0.22	0.21	0.23	0.2	0.2	0.23	0.23	0.24	0.22	0.21	0.18	0.23	0.22	0.18
Cu	—	0.1	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.01
Zn	—	0.1	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	<0.01	0.01	0.02	<0.01
Remark			85414 008-07389	85454 004-01499	85450 008-05788	85451 004-01497	85452 004-01498	85451 004-01355	85450 008-07279	85454 004-01357	85452 004-01356	69541 008-05313	69539 004-05497	69537 69540 004-05928 ※	69542 008-05314	69538 004-05922

※Sample No.1

<A5052>Unit : %

Elements	Standard value		A52-1		A52-2	A52-3	
	Lower	Upper	—		—	Reflector	Plug et al
Mg	2.2	2.8	2.53	2.46	2.63	2.39	2.6
Al	—	—	—	—	—	—	—
Si	—	0.25	0.123	0.082	0.127	—	0.09
Ti	—	—	—	—	—	—	—
Cr	0.15	0.35	0.205	0.217	0.239	0.21	0.26
Mn	—	0.1	0.048	0.056	0.034	0.06	0.01
Fe	—	0.4	0.235	0.299	0.192	—	0.26
Cu	—	0.1	0.06	0.038	0.055	0.05	0.07
Zn	—	0.1	0.04	0.01	0.038	0.03	0.01
Remark			40600	41800	83046	83831	004-09615 ※

※Sample No.2

Table 3 Chemical components listed in the mill test certificate of aluminum alloy (2/2)

<A6061>Unit : %

Elements	Standard value		A61-1			A61-2			A61-3	A61-4		A61-5		
	Lower	Upper	—			Reflector	Lower plug	Plug	—	Reflector	Lower plug	Reflector	Plug	Lower plug
Mg	0.8	1.2	1.06	1.04	1	0.94	0.86	0.87	0.92	0.93	0.88	1.0	0.9	1.0
Al	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Si	0.4	0.8	0.56	0.56	0.61	0.66	0.54	0.63	0.58	0.74	0.68	0.66	0.65	0.66
Ti	—	0.15	0.04	0.04	0.04	0.03	0.04	0.04	0.03	0.02	0.04	0.01	002	0.01
Cr	0.04	0.35	0.27	0.21	0.19	0.07	0.07	0.09	0.08	0.04	0.08	0.08	0.07	0.08
Mn	—	0.15	0.05	0.06	0.04	0.02	0.02	0.02	0.03	0.01	0.02	0.01	0.01	0.01
Fe	—	0.7	0.37	0.41	0.36	0.34	0.31	0.34	0.34	0.2	0.35	0.2	0.2	0.2
Cu	0.15	0.4	0.23	0.32	0.24	0.2	0.22	0.24	0.2	0.32	0.22	0.34	0.33	0.34
Zn	—	0.25	0.06	0.06	0.05	0.06	0.04	0.02	0.05	0.02	<0.01	0.01	0.01	0.01
Remark			44494	44337	43447	92397	91590	48561 ※	136405	120618	E13629	493231100	484261900	49320100

※Sample No.3

<A1050>Unit : %

Elements	Standard value		75F-4A		75F-5A	76F-4A	HR
	Lower	Upper	Spacer block	Heat medium	Heat medium	—	—
Mg	—	0.05	—	0.01	—	—	0.01
Al	99.5	—	99.7	99.55	99.66	99.64	99.62
Si	—	0.25	0.06	0.09	0.09	0.1	0.09
Ti	—	0.03	0.01	0.01	—	—	0.01
Cr	—	—	—	—	—	—	—
Mn	—	0.05	—	—	—	—	—
Fe	—	0.4	0.17	0.29	0.25	0.26	0.26
Cu	—	0.05	0.01	0.03	—	—	0.01
Zn	—	0.05	0.01	0.02	—	—	0.01
Remark			20307				※

※Sample No.4

Table 4　Manufacturing history of the beryllium frame (beryllium plugs)

No.	Structural material name	Quantity	Main material	Manufacturing year	Manufacturer
Be-1	Beryllium frame (1st gen) Beryllium plug No.1-17(ϕ32) No.18-24(ϕ38)※1	24	Be	S42 (1967)	NGK Insulators, Ltd. (NGK)
Be-2	Beryllium frame (2nd gen) Beryllium plug No.31-46(ϕ32) No.47-52(ϕ38)※2	22		S50 (1976)	Kawecki Berylco Industries (KBI)
Be-3	Beryllium frame (3rd gen)	―		S56 (1981)	Brush Wellman (BRUSH)
Be-4	Beryllium frame (4th gen) Beryllium plug No.53-74(ϕ40)	22		H1 (1989)	
Be-5	Beryllium frame (5th gen) Beryllium plug No.75-79(ϕ40)※3	5		H8 (1996)	
Be-6	Beryllium frame (6th gen)	―		H13 (2001)	
Be-7	Beryllium frame (7th gen) Beryllium plug	22		H21 (2009)	

※1：Sample No.5

※2：Sample No.6

※3：Sample No.7

Table 5　Chemical components listed in the mill test certificate of the beryllium (1/2)

(Unit：Be%, others ppm)

Elements	Standard value		No.Be-1						No.Be-2	
	Lower	Upper	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Be	98	—	98.67	98.41	98.44	98.36	98.41	98.36	98.65	98.64
Fe	—	1600	960	1020	740	700	800	930	1230	1210
C	—	1500	950	810	1050	930	1030	920	650	650
Al	—	1000	430	500	230	260	250	220	240	270
Mg	—	500	40	50	70	70	80	90	30	30
Si	—	800	260	240	210	280	210	190	260	280
N	—	500	280	290	290	330	310	320	200	200
Mn	—	150	50	50	60	80	50	50	80	80
Cr	—	200	60	60	50	60	50	50	100	100
Ni	—	300	140	120	120	150	120	100	170	160
Ag	—	10	7	8	7	8	7	8	<1	<1
Ca	—	200	70	70	60	80	60	60	<200	<200
Co	—	5～10	<5	<5	<5	<5	<5	<5	<5	<5
Cu	—	150	80	60	80	60	70	80	50	50
Cd	—	2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Mo	—	20	<8	<8	<8	<8	<8	<8	<10	<10
Pb	—	20	<5	<5	<5	<5	<5	<5	10	3
Li	—	3	1.1	1	1.2	1.1	1.2	1.1	<1	<1
B	—	2～5	<2	<2	<2	<2	<2	<2	<1	<1
Cl	—	400	28	30	22	72	22	18	<50	<50
Remarks			P-3(E2W) ※1		P-4(E1) ※1		P-5(E3W) ※1		Lot No.628 ※2	

※1：Sample No.5

※2：Sample No.6

Table 5　Chemical components listed in the mill test certificate of the beryllium (2/2)

(Unit：Be%, others ppm)

Elements	Standard value		No.Be-3		No.Be-4		No.Be-5		No.Be-6	
	Lower	Upper	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Be	98	—	99.0	98.9	99.29	99.24	98.86	98.96	99.14	99.01
Fe	—	1600	730	722	890	890	990	995	1030	1050
C	—	1500	1400	1060	1040	850	1250	730	520	680
Al	—	1000	380	380	300	300	375	380	420	260
Mg	—	500	260	290	100	295	100	270	130	160
Si	—	800	300	270	280	280	275	270	280	255
N	—	500	242	254	245	195	250	240	240	235
Mn	—	150	45	50	50	50	80	80	85	100
Cr	—	200	75	70	70	70	85	90	65	65
Ni	—	300	100	100	90	95	120	120	125	125
Ag	—	10	<3	<3	<3	<3	<3	<3	<3	<3
Ca	—	200	<85	<85	<20	<20	<20	<20	<20	<20
Co	—	5～10	9	9	7	8	4	5	4	4
Cu	—	150	50	55	20	15	65	60	50	50
Cd	—	2	<2	<2	<2	<2	<2	<2	<2	<2
Mo	—	20	10	10	<20	<20	<8	<8	<20	<20
Pb	—	20	<6	<6	<20	<20	<6	<6	<20	<20
Li	—	3	<3	<3	<3	<3	<3	<3	<3	<3
B	—	2～5	3	2.7	<2	<2	<2	<2	<2	<2
Cl	—	400	<25	<25	<5	<5	50	35	<400	<400
Remarks			Lot No.2318		Lot No.4283		Lot No.4996 ※3		Lot No.5113	

※3：Sample No.7

Table 6　Manufacturing history of the hafnium

No.	Structural material name	Quantity	Main material	Manufacturing year	Manufacturer
—	Control rod (Neutron absorber) (No.1-10)	10	Hf	S42- (1967-)	Nuclear Materials and Equipment Corporation
—	Control rod (Neutron absorber) (No.11-12)	2		S45- (1970-)	
—	Control rod (Neutron absorber) (No.13)	1		S46- (1971-)	
Hf-1	Control rod (Neutron absorber) (No.14-18)	5		S63-H2 (1988-1990)	Cezus
Hf-2	Control rod (Neutron absorber) (No.19-21)※1	3		H3-H4 (1991-1992)	
	Control rod (Neutron absorber) (No.22-24)※2	3		H7-H8 (1995-1996)	
Hf-3	Control rod (Neutron absorber) (No.25-27)※3	3		H10-H11 (1998-1999)	

※1 : Sample No.10. The analysis sample is a preliminary welding test piece made from the same lot.

※2 : Sample No.8

※3 : Sample No.9

Table 7　Chemical components listed in the mill test certificate of the hafnium

(Unit : Hf, Zr%, Others ppm)

Elements	Standard value		Hf-1		Hf-2					Hf-3		
	Lower	Upper	Top	Bottom	Top	M-Top	M-Middle	M-Bottom	Bottom	Top	Middle	Bottom
Hf	95.3	—	>98	>98	>95.3	>95.3	>95.3	>95.3	>95.3	>95.3	>95.3	>95.3
Zr	—	4.5	1.05	1.05	0.8	0.86	0.87	0.86	0.83	0.59	0.49	0.47
Al	—	100	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
B	—	—	—	—	<0.4	<0.4	<0.4	—	—	—	—	—
C	—	150	36	25	21	13	13	18	27	36	40	45
Co	—	—	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cu	—	100	<10	<10	17	10	10	<10	<10	<10	<10	<10
H	—	25	6	9	3	<3	4	<3	<3	5	3	6
Mg	—	—	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Mn	—	—	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Mo	—	20	<5	<5	6	5	<5	<5	<5	<5	8	<5
N	—	100	25	34	31	30	27	16	26	14	21	17
Nb	—	100	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Ni	—	50	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
O	—	400	210	330	280	270	270	280	240	300	320	250
P	—	—	—	—	<5	<5	<5	—	—	—	—	—
Pb	—	—	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Si	—	100	<25	<25	<25	<25	<25	<25	<25	<30	<30	<30
Ta	—	200	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Ti	—	100	<10	<10	<10	<10	<10	<10	<10	10	10	<10
U	—	10	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
V	—	50	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
W	—	150	<10	<10	14	<10	<10	<10	<10	<15	21	<15
Cr	—	100	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Fe	—	250～500	41	43	<20	<20	<20	<20	<20	311	350	317
Sn	—	50	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Remarks			222437		240672 ※1					246459 ※2		

※1 : Sample No.8, 10

※2 : Sample No.9

Table 8 Chemical components listed in the mill test certificate of stainless steel

(Unit：%)

Elements	Standard value		SUS304	Standard value		SUS630
	Lower	Upper		Lower	Upper	
C	—	0.08	0.05	—	0.07	0.05
Si	—	1.00	0.28	—	1.00	0.19
Mn	—	2.00	1.73	—	1.00	0.92
P	—	0.045	0.038	—	0.040	0.020
S	—	0.030	0.026	—	0.030	0.003
Ni	8.00	10.50	8.29	3.00	5.00	4.36
Cr	18.00	20.00	18.83	15.00	17.50	15.04
Cu	—	—	—	3.00	5.00	3.46
Nb	—	—	—	0.15	0.45	0.28
Remarks	—		N111693 ※1	—		N981547 ※2

※1：Sample No.12

※2：Sample No.13

Table 9 Target elements of analysis (1/2)

Atomic No.	Chemical symbol	Target elements of analysis	Analytical method	
			GD-MS	Others
1	H	○	—	Inert gas fusion - Thermal conductivity method (Reference specification: JIS H 1619)
2	He			
3	Li	○	○	
4	Be	○	○	
5	B	○	○	
6	C	○	—	Combustion - Infrared absorbing method (Reference specification: JIS G 1211)
7	N	○	—	Inert gas fusion - Thermal conductivity method (Reference specification: JIS G 1228)※2 Ammonia distillation separation indophenol blue absorptiometry (Reference specification: JIS G 1228)※3
8	O	○	—	Inert gas fusion - Infrared absorbing method (Reference specification: JIS G 1239)
9	F	○※1	○	
10	Ne			
11	Na	○	○	
12	Mg	○	○	
13	Al	○	○	
14	Si	○	○	
15	P	○	○	
16	S	○	○	
17	Cl	○	○	
18	Ar			
19	K	○	○	
20	Ca	○	○	
21	Sc	○	○	
22	Ti	○	○	
23	V	○	○	
24	Cr	○	○	
25	Mn	○	○	
26	Fe	○	○	
27	Co	○	○	
28	Ni	○	○	
29	Cu	○	○	
30	Zn	○	○	
31	Ga	○	○	
32	Ge	○	○	
33	As	○	○	
34	Se	○	○	
35	Br	○	○	
36	Kr			
37	Rb	○	○	
38	Sr	○	○	
39	Y	○	○	
40	Zr	○	○	
41	Nb	○	○	
42	Mo	○	○	
43	Tc			
44	Ru	○	○	
45	Rh	○	○	
46	Pd	○	○	

※1：Except Sample No.1　※2：Sample No.5-13　※3：Sample No.1-4

Table 9　Target elements of analysis (2/2)

Atomic No.	Chemical symbol	Target elements of analysis	Analytical method	
			GD-MS	Others
47	Ag	○	○	
48	Cd	○	○	
49	In	○	○	
50	Sn	○	○	
51	Sb	○	○	
52	Te	○	○	
53	I	○※1	○	
54	Xe			
55	Cs	○	○	
56	Ba	○	○	
57	La	○	○	
58	Ce	○	○	
59	Pr	○	○	
60	Nd	○	○	
61	Pm			
62	Sm	○	○	
63	Eu	○	○	
64	Gd	○	○	
65	Tb	○	○	
66	Dy	○	○	
67	Ho	○	○	
68	Er	○	○	
69	Tm	○	○	
70	Yb	○	○	
71	Lu	○	○	
72	Hf	○	○	
73	Ta	○	○	
74	W	○	○	
75	Re	○	○	
76	Os	○	○	
77	Ir	○	○	
78	Pt	○	○	
79	Au	○	○	
80	Hg	○	○	
81	Tl	○	○	
82	Pb	○	○	
83	Bi	○	○	
84	Po			
85	At			
86	Rn			
87	Fr			
88	Ra			
89	Ac			
90	Th	○	—	Inductively Coupled Plasma Mass Spectrometry (ICP-MS)
91	Pa			
92	U	○	—	Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

※1：Except Sample No.1

Table 10　Main specifications of the analyzer used

Glow Discharge Mass Spectrometer (GD-MS)	
Analyzer	Glow Discharge Mass Spectrometer Astrum（Nu Instruments）
Gas discharge	High-purity argon
Discharge condition	2mA 1kV
Resolution	About 4000
Reset time	Faraday cup：100msec×100ch×1scan Multiplier：100～320msec×100ch×1～5scan

Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	
Analyzer	Inductively Coupled Plasma Mass Spectrometry Agilent 7700x (Agilent Technologies)

Inert gas fusion - Thermal conductivity method or Infrared absorbing method	
Analyzer	Hydrogen analyzer RH-404 (LECO) Oxygen nitrogen argon analyzer EMGA-920 type-Ar (HORIBA, Ltd.)

Combustion - Infrared absorbing method	
Analyzer	Carbon sulfur analyzer CS-844（LECO）

Ammonia distillation separation indophenol blue absorptiometry	
Analyzer	Ultraviolet and visible spectrophotometer UV-2600 (Shimadzu Corporation)

Table 11 Results of elemental composition analysis of the aluminum alloy (1/2)

Atomic No.	Chemical symbol	Results (ppm)				Avg (ppm)	SD (ppm)	SD/Avg (%)
		Sample No.1 (A6063)	Sample No.2 (A5052)	Sample No.3 (A6061)	Sample No.4 (A1050)			
1	H	< 1	< 1	< 1	< 1	1	—	—
2	He							
3	Li	0.05	< 0.01	< 0.01	0.05	0.03	0.02	77.0
4	Be	0.06	0.54	0.94	0.01	0.39	0.44	113.3
5	B	1.2	1.8	2	2.9	2.0	0.7	35.7
6	C	< 50	< 50	< 50	< 50	50	—	—
7	N	< 10	< 10	< 10	< 10	10	—	—
8	O	< 50	< 50	< 50	< 50	50	—	—
9	F	—	0.02※1	0.03※1	0.51※1	0.19	0.28	150.0
10	Ne							
11	Na	0.70	0.03	0.07	0.27	0.27	0.31	114.7
12	Mg	5000	24000	8400	92	9373	10330	110.2
13	Al	Matrix	Matrix	Matrix	Matrix			
14	Si	4200	1000	6500	920	3155	2703	85.7
15	P	1.7	3.2	1.4	1.9	2.1	0.8	38.7
16	S	0.20	0.97	0.45	0.15	0.44	0.38	84.8
17	Cl	0.11※1	2.9※1	1※1	0.05※1	1.0	1.3	131.0
18	Ar							
19	K	< 0.01	0.05	0.05	0.08	0.05	0.03	60.5
20	Ca	0.67	< 0.01	0.29	1.1	0.52	0.47	91.4
21	Sc	0.08	0.04	0.06	0.04	0.06	0.02	34.8
22	Ti	48	51	430	190	179.8	179.5	99.9
23	V	55	37	73	74	60	18	29.3
24	Cr	37	2600	1100	11	937	1219	130.1
25	Mn	110	170	340	32	163	131	80.3
26	Fe	2000	2700	3600	2600	2725	660	24.2
27	Co	0.92	0.71	1.6	0.56	0.95	0.46	48.5
28	Ni	25	21	64	34	36	19	54.0
29	Cu	210	650	2200	90	788	972	123.4
30	Zn	200	110	320	62	173	113	65.6
31	Ga	110	120	120	110	115	6	5.0
32	Ge	1.1	0.56	0.58	0.6	0.7	0.3	36.7
33	As	0.06	0.02	0.04	0.04	0.04	0.02	40.8
34	Se	< 0.01	0.12	< 0.01	< 0.01	0.04	0.06	146.7
35	Br	< 0.01※1	0.17※1	0.08※1	< 0.01※1	0.07	0.08	112.4
36	Kr							
37	Rb	< 0.01※1	< 0.01※1	< 0.01※1	< 0.01※1	0.01	—	—
38	Sr	0.14	0.12	1.4	0.75	0.603	0.607	100.7
39	Y	0.17	0.06	0.16	0.06	0.11	0.06	54.0
40	Zr	12	7.3	36	5.8	15	14	92.1
41	Nb	0.21	0.3	0.39	0.19	0.27	0.09	33.7
42	Mo	0.22	1.2	3.3	1.9	1.7	1.3	78.3
43	Tc							
44	Ru	< 0.01	0.05	0.1	< 0.01	0.043	0.043	100.5
45	Rh	0.65	0.76	0.51	0.87	0.7	0.2	22.1
46	Pd	< 0.01	< 0.01	0.09	0.02	0.03	0.04	118.8

※1 : GD-MS is RSF (Relative Sensitivity Factors) converted concentration expressed with Al as 100%. For elements whose RSF is unknown, analysis values are calculated using ionic strength.

Table 11　Results of elemental composition analysis of the aluminum alloy (2/2)

Atomic No.	Chemical symbol	Results (ppm)				Avg (ppm)	SD (ppm)	SD/Avg (%)
		Sample No.1 (A6063)	Sample No.2 (A5052)	Sample No.3 (A6061)	Sample No.4 (A1050)			
47	Ag	0.08	0.04	0.19	0.03	0.09	0.07	86.2
48	Cd	0.40	0.14	0.41	0.24	0.3	0.1	43.9
49	In	0.22	0.15	0.09	0.22	0.2	0.1	36.9
50	Sn	12	6.6	7.2	2	7	4	58.9
51	Sb	0.03	< 0.01	0.08	< 0.01	0.03	0.03	101.7
52	Te	< 0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
53	I	—	< 0.01※1	< 0.01※1	< 0.01※1	0.01	—	—
54	Xe							
55	Cs	< 0.01※1	< 0.01※1	< 0.01※1	< 0.01※1	0.01	—	—
56	Ba	< 0.01	< 0.01	< 0.01	0.02	0.013	0.005	40.0
57	La	0.46	0.08	0.26	0.15	0.24	0.17	69.8
58	Ce	0.56	0.11	0.43	0.27	0.34	0.20	57.0
59	Pr	0.08	0.02	0.05	0.04	0.05	0.03	52.6
60	Nd	0.27	0.12	0.2	0.13	0.18	0.07	38.8
61	Pm							
62	Sm	0.02	< 0.01	< 0.01	< 0.01	0.013	0.005	40.0
63	Eu	< 0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
64	Gd	0.06	< 0.01	0.01	< 0.01	0.02	0.03	111.1
65	Tb	< 0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
66	Dy	0.05	< 0.01	0.01	< 0.01	0.02	0.02	100.0
67	Ho	< 0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
68	Er	0.02	< 0.01	0.01	< 0.01	0.013	0.005	40.0
69	Tm	< 0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
70	Yb	0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
71	Lu	< 0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
72	Hf	0.91	0.16	0.41	0.15	0.41	0.36	87.3
73	Ta	< 1※2	< 2※2	< 0.5※2	< 0.9※2	1.1	0.6	58.0
74	W	0.56	0.28	0.45	0.24	0.38	0.15	39.0
75	Re	< 0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
76	Os	< 0.01※1	< 0.01※1	< 0.01※1	< 0.01※1	0.01	—	—
77	Ir	< 0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
78	Pt	< 0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
79	Au	< 0.01	< 0.01	0.02	< 0.01	0.013	0.005	40.0
80	Hg	< 0.01	< 0.01	< 0.01	< 0.01	0.01	—	—
81	Tl	0.20	0.14	0.11	0.42	0.22	0.14	64.4
82	Pb	16	25	21	25	22	4	19.6
83	Bi	1.3	5.1	4.7	0.05	2.8	2.5	89.6
84	Po							
85	At							
86	Rn							
87	Fr							
88	Ra							
89	Ac							
90	Th	0.086	0.13	0.12	0.072	0.10	0.03	26.9
91	Pa							
92	U	0.81	1.7	0.8	0.44	0.94	0.54	57.2

※1 : GD-MS is RSF (Relative Sensitivity Factors) converted concentration expressed with Al as 100%. For elements whose RSF is unknown, analysis values are calculated using ionic strength.

※2 : Regarding Ta, the analysis value includes contamination from discharge cells, etc.

Table 12 Results of elemental composition analysis of the beryllium (1/2)

Atomic No.	Chemical symbol	Results (ppm)			Avg (ppm)	SD (ppm)	SD/Avg (%)
		Sample No.5 (Be)	Sample No.6 (Be)	Sample No.7 (Be)			
1	H	< 1	1	1	1		
2	He						
3	Li	0.67	< 0.01	< 0.01	0.2	0.4	165.7
4	Be	Matrix	Matrix	Matrix			
5	B	0.59	0.47	1.2	0.8	0.4	52.0
6	C	1200	600	800	867	306	35.3
7	N	< 500	< 500	< 500	500		
8	O	5900	6200	7100	6400	624	9.8
9	F	0.18[※1]	0.05[※1]	0.09[※1]	0.11	0.07	62.4
10	Ne						
11	Na	0.25	0.07	0.15	0.16	0.09	57.6
12	Mg	120	1.8	100	74	63	85.6
13	Al	210	120	140	157	47	30.2
14	Si	190	120	120	143	40	28.2
15	P	2.7	1.8	0.54	1.7	1.1	64.6
16	S	6.8	9.9	9.3	8.7	1.6	19.0
17	Cl	6.2[※1]	3.7[※1]	7.5[※1]	5.8	1.9	33.3
18	Ar						
19	K	0.44	< 0.01	1	0.48	0.50	102.7
20	Ca	7	3.8	1.7	4.2	2.7	64.1
21	Sc	1.4	0.59	0.14	0.7	0.6	89.9
22	Ti	41	17	7.9	22	17	77.8
23	V	1.3	0.68	2	1.3	0.7	49.8
24	Cr	38	41	40	40	2	3.9
25	Mn	22	25	30	26	4	15.7
26	Fe	360	470	330	387	74	19.1
27	Co	1.6	3	1.8	2.1	0.8	35.5
28	Ni	69	78	50	66	14	21.8
29	Cu	31	33	26	30	4	12.0
30	Zn	0.1	0.38	0.43	0.3	0.2	58.6
31	Ga	0.22	0.08	0.13	0.14	0.07	49.5
32	Ge	< 0.01	< 0.01	< 0.01	0.01		
33	As	0.03	0.02	0.03	0.03	0.01	21.7
34	Se	< 0.01	< 0.01	< 0.01	0.01		
35	Br	3.9[※1]	16[※1]	0.58[※1]	7	8	118.9
36	Kr						
37	Rb	< 0.01[※1]	< 0.01[※1]	< 0.01[※1]	0.01		
38	Sr	0.11	0.06	0.02	0.06	0.05	71.2
39	Y	< 0.01	0.03	0.06	0.03	0.03	75.5
40	Zr	2.1	1.4	8.6	4.0	4.0	98.4
41	Nb	0.21	0.18	0.12	0.17	0.05	27.0
42	Mo	4.7	3	3	4	1	27.5
43	Tc						
44	Ru	< 0.01	< 0.01	< 0.01	0.01		
45	Rh	< 0.01	< 0.01	< 0.01	0.01		
46	Pd	< 0.01	< 0.01	< 0.01	0.01		

※1 : GD-MS is RSF (Relative Sensitivity Factors) converted concentration expressed with Be as 100%. For elements whose RSF is unknown, analysis values are calculated using ionic strength.

Table 12 Results of elemental composition analysis of the beryllium (2/2)

Atomic No.	Chemical symbol	Results (ppm)			Avg (ppm)	SD (ppm)	SD/Avg (%)
		Sample No.5 (Be)	Sample No.6 (Be)	Sample No.7 (Be)			
47	Ag	1.4	0.45	0.15	0.67	0.65	97.9
48	Cd	< 0.01	< 0.01	< 0.01	0.01		
49	In	2.4	1.3	0.04	1.25	1.18	94.7
50	Sn	2.3	0.3	0.13	0.9	1.2	132.6
51	Sb	0.05	0.07	0.17	0.10	0.06	66.5
52	Te	< 0.01	< 0.01	< 0.01	0.01		
53	I	0.01[※1]	0.02[※1]	0.01[※1]	0.013	0.006	43.3
54	Xe						
55	Cs	< 0.01[※1]	< 0.01[※1]	< 0.01[※1]	0.01		
56	Ba	< 0.01	< 0.01	< 0.01	0.01		
57	La	< 0.01	< 0.01	< 0.01	0.01		
58	Ce	0.02	< 0.01	0.06	0.030	0.026	88.2
59	Pr	< 0.01	< 0.01	< 0.01	0.01		
60	Nd	< 0.01	< 0.01	0.04	0.020	0.017	86.6
61	Pm						
62	Sm	< 0.01	< 0.01	< 0.01	0.01		
63	Eu	< 0.01	< 0.01	< 0.01	0.01		
64	Gd	< 0.01	< 0.01	< 0.01	0.01		
65	Tb	< 0.01	< 0.01	< 0.01	0.01		
66	Dy	< 0.01	< 0.01	< 0.01	0.01		
67	Ho	< 0.01	< 0.01	< 0.01	0.01		
68	Er	< 0.01	< 0.01	< 0.01	0.01		
69	Tm	< 0.01	< 0.01	< 0.01	0.01		
70	Yb	< 0.01	< 0.01	< 0.01	0.01		
71	Lu	< 0.01	< 0.01	< 0.01	0.01		
72	Hf	0.05	0.05	0.13	0.08	0.05	60.2
73	Ta	< 5[※2]	< 5[※2]	< 6[※2]	5.3	0.6	10.8
74	W	8.5	5.1	5.3	6	2	30.3
75	Re	< 0.01	< 0.01	< 0.01	0.01		
76	Os	< 0.01[※1]	< 0.01[※1]	< 0.01[※1]	0.01		
77	Ir	< 0.01	< 0.01	< 0.01	0.01		
78	Pt	0.09	0.06	< 0.01	0.05	0.04	75.8
79	Au	< 0.01	0.25	3.6	1.3	2.0	156.0
80	Hg	< 0.01	< 0.01	< 0.01	0.01		
81	Tl	< 0.01	< 0.01	< 0.01	0.01		
82	Pb	0.52	0.99	0.24	0.6	0.4	65.0
83	Bi	0.34	2.1	< 0.01	0.8	1.1	137.6
84	Po						
85	At						
86	Rn						
87	Fr						
88	Ra						
89	Ac						
90	Th	0.82	0.19	0.1	0.37	0.39	106.0
91	Pa						
92	U	6	30	55	30	25	80.8

※1 : GD-MS is RSF (Relative Sensitivity Factors) converted concentration expressed with Be as 100%. For elements whose RSF is unknown, analysis values are calculated using ionic strength.

※2 : Regarding Ta, the analysis value includes contamination from discharge cells, etc.

Table 13 Results of elemental composition analysis of the hafnium (1/2)

Atomic No.	Chemical symbol	Results (ppm)			Avg (ppm)	SD (ppm)	SD/Avg (%)
		Sample No.8 (Hf)	Sample No.9 (Hf)	Sample No.10 (Hf)			
1	H	2	3	< 1	2	1	50.0
2	He						
3	Li	< 0.01	< 0.01	< 0.01	0.01		
4	Be	< 0.01	< 0.01	< 0.01	0.01		
5	B	0.02	0.05	0.02	0.03	0.02	57.7
6	C	< 20	50	< 20	30	17	57.7
7	N	< 50	< 50	< 50	50		
8	O	280	340	260	293	42	14.2
9	F	0.05※1	0.31※1	0.22※1	0.19	0.13	68.3
10	Ne						
11	Na	< 0.01	< 0.01	0.01	0.01		
12	Mg	< 0.01	< 0.01	< 0.01	0.01		
13	Al	0.98	1.6	0.31	1.0	0.6	67.0
14	Si	4.1	9.1	4.7	6.0	2.7	45.8
15	P	0.08	0.8	0.21	0.4	0.4	105.6
16	S	3.5	4.4	2.9	3.6	0.8	21.0
17	Cl	0.03※1	0.07※1	0.02※1	0.04	0.03	66.1
18	Ar						
19	K	< 0.01	< 0.01	< 0.01	0.01		
20	Ca	< 0.01	< 0.01	< 0.01	0.01		
21	Sc	0.2	0.06	0.11	0.12	0.07	57.5
22	Ti	1.3	16	1.4	6.2	8.5	135.7
23	V	0.03	0.19	0.04	0.087	0.090	103.4
24	Cr	0.14	5.5	0.11	1.9	3.1	161.9
25	Mn	< 0.01	0.13	< 0.01	0.05	0.07	138.6
26	Fe	2.7	600	11	205	342	167.4
27	Co	< 0.01	1.6	0.02	0.5	0.9	168.4
28	Ni	2.2	13	3.4	6.2	5.9	95.5
29	Cu	1.5	1.9	2.3	1.9	0.4	21.1
30	Zn	< 0.01	< 0.01	< 0.01	0.01		
31	Ga	< 0.01	< 0.01	< 0.01	0.01		
32	Ge	< 0.01	< 0.01	< 0.01	0.01		
33	As	< 0.01	0.06	< 0.01	0.027	0.029	108.3
34	Se	< 0.01	< 0.01	< 0.01	0.01		
35	Br	< 0.01※1	< 0.01※1	< 0.01※1	0.01		
36	Kr						
37	Rb	< 0.01※1	< 0.01※1	< 0.01※1	0.01		
38	Sr	< 0.01	0.03	< 0.01	0.02	0.01	69.3
39	Y	< 0.01	< 0.01	< 0.01	0.01		
40	Zr	12000	5300	13000	10100	4187	41.5
41	Nb	0.68	4.4	5.9	3.7	2.7	73.4
42	Mo	2.7	17	2.2	7.3	8.4	115.1
43	Tc						
44	Ru	< 0.01	< 0.01	< 0.01	0.01		
45	Rh	< 0.01	< 0.01	< 0.01	0.01		
46	Pd	0.04	< 0.01	< 0.01	0.020	0.017	86.6

※1 : GD-MS is RSF (Relative Sensitivity Factors) converted concentration expressed with Hf as 100%. For elements whose RSF is unknown, analysis values are calculated using ionic strength.

Table 13　Results of elemental composition analysis of the hafnium (2/2)

Atomic No.	Chemical symbol	Results (ppm)			Avg (ppm)	SD (ppm)	SD/Avg (%)
		Sample No.8 (Hf)	Sample No.9 (Hf)	Sample No.10 (Hf)			
47	Ag	< 0.01	< 0.01	< 0.01	0.01		
48	Cd	< 0.01	< 0.01	< 0.01	0.01		
49	In	< 0.01	< 0.01	< 0.01	0.01		
50	Sn	0.15	0.37	0.13	0.2	0.1	61.5
51	Sb	< 0.01	< 0.01	< 0.01	0.01		
52	Te	< 0.01	< 0.01	< 0.01	0.01		
53	I	< 0.01※1	< 0.01※1	< 0.01※1	0.01		
54	Xe						
55	Cs	< 0.01※1	< 0.01※1	< 0.01※1	0.01		
56	Ba	< 0.01	< 0.01	< 0.01	0.01		
57	La	< 0.01	< 0.01	< 0.01	0.01		
58	Ce	< 0.01	< 0.01	< 0.01	0.01		
59	Pr	< 0.01	< 0.01	< 0.01	0.01		
60	Nd	< 0.01	< 0.01	< 0.01	0.01		
61	Pm						
62	Sm	< 0.01	< 0.01	< 0.01	0.01		
63	Eu	< 0.01	< 0.01	< 0.01	0.01		
64	Gd	< 0.01	< 0.01	< 0.01	0.01		
65	Tb	< 0.01	< 0.01	< 0.01	0.01		
66	Dy	< 0.01	< 0.01	< 0.01	0.01		
67	Ho	< 0.01	< 0.01	< 0.01	0.01		
68	Er	< 0.01	< 0.01	< 0.01	0.01		
69	Tm	< 0.01	< 0.01	< 0.01	0.01		
70	Yb	< 0.01	< 0.01	< 0.01	0.01		
71	Lu	< 0.01	< 0.01	< 0.01	0.01		
72	Hf	Matrix	Matrix	Matrix			
73	Ta	< 4※2	< 8※2	< 7※2	6.3	2.1	32.9
74	W	12	34	11	19	13	68.4
75	Re	< 0.01	< 0.01	< 0.01	0.01		
76	Os	< 0.01※1	< 0.01※1	< 0.01※1	0.01		
77	Ir	< 0.01	< 0.01	< 0.01	0.01		
78	Pt	< 0.01	< 0.01	< 0.01	0.01		
79	Au	< 0.01	< 0.01	< 0.01	0.01		
80	Hg	< 0.01	< 0.01	< 0.01	0.01		
81	Tl	< 0.01	< 0.01	< 0.01	0.01		
82	Pb	< 0.01	< 0.01	< 0.01	0.01		
83	Bi	< 0.01	< 0.01	< 0.01	0.01		
84	Po						
85	At						
86	Rn						
87	Fr						
88	Ra						
89	Ac						
90	Th	0.09	0.1	0.08	0.09	0.01	11.1
91	Pa						
92	U	< 0.005	< 0.005	< 0.005	0.005		

※1 : GD-MS is RSF (Relative Sensitivity Factors) converted concentration expressed with Hf as 100%. For elements whose RSF is unknown, analysis values are calculated using ionic strength.
※2 : Regarding Ta, the analysis value includes contamination from discharge cells, etc.

Table 14 Results of elemental composition analysis of the lead and the stainless steel (1/2)

Atomic No.	Chemical symbol	Results (ppm)		
		Sample No.11 (Pb)	Sample No.12 (SUS304)	Sample No.13 (SUS630)
1	H	< 1	2	< 1
2	He			
3	Li	< 0.01	< 0.01	< 0.01
4	Be	< 0.01	< 0.01	< 0.01
5	B	< 0.01	1.4	2.3
6	C	10	540	780
7	N	< 50	830	480
8	O	< 50	80	26
9	F	< 0.01[※1]	< 0.01[※1]	< 0.01[※1]
10	Ne			
11	Na	< 0.01	0.01	< 0.01
12	Mg	< 0.01	0.36	0.01
13	Al	0.36	5.2	55
14	Si	< 0.01	2100	1700
15	P	< 0.01	300	170
16	S	0.15	210	26
17	Cl	0.05[※1]	0.03[※1]	0.02[※1]
18	Ar			
19	K	< 0.01	0.01	< 0.01
20	Ca	< 0.01	0.49	0.09
21	Sc	< 0.01	0.03	0.03
22	Ti	< 0.01	2.4	3.1
23	V	< 0.01	1000	360
24	Cr	0.02	150000	120000
25	Mn	< 0.01	14000	7200
26	Fe	0.06	790000	850000
27	Co	< 0.01	1400	380
28	Ni	0.02	70000	40000
29	Cu	2.4	3500	27000
30	Zn	< 0.01	4.5	3.6
31	Ga	< 0.01	54	42
32	Ge	< 0.01	31	20
33	As	0.08	31	19
34	Se	< 0.01	0.13	< 0.01
35	Br	< 0.01[※1]	< 0.01[※1]	< 0.01[※1]
36	Kr			
37	Rb	< 0.01[※1]	0.02[※1]	0.02[※1]
38	Sr	< 0.01	0.4	0.19
39	Y	< 0.01	0.09	0.06
40	Zr	0.14	27	13
41	Nb	< 0.01	120	2200
42	Mo	< 0.01	2200	1600
43	Tc			
44	Ru	< 0.01	0.22	0.16
45	Rh	< 0.01	0.05	1.3
46	Pd	< 0.01	0.24	0.21

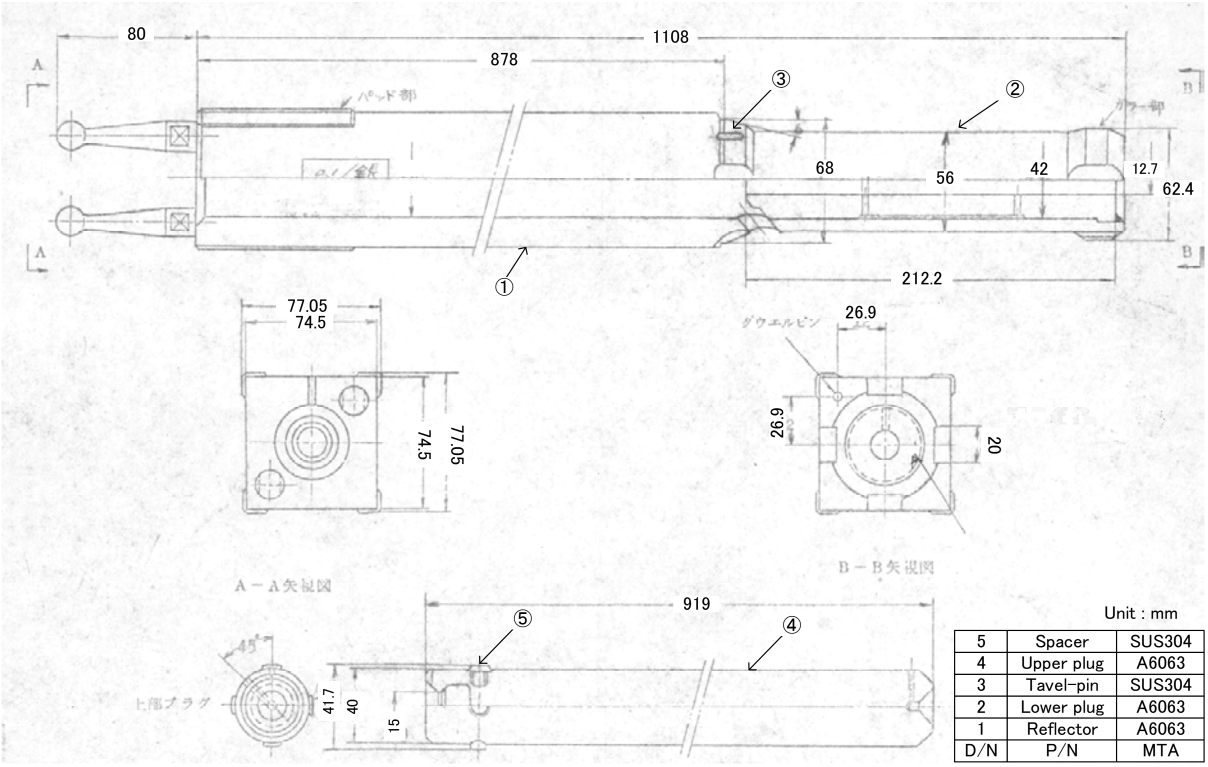
※1 : GD-MS is RSF (Relative Sensitivity Factors) converted concentration expressed with Pb or Fe+Cr+Ni as 100%. For elements whose RSF is unknown, analysis values are calculated using ionic strength.

Table 14 Results of elemental composition analysis of the lead and the stainless steel (2/2)

Atomic No.	Chemical symbol	Results (ppm)		
		Sample No.11 (Pb)	Sample No.12 (SUS304)	Sample No.13 (SUS630)
47	Ag	1.5	0.52	0.22
48	Cd	0.08	< 0.01	0.02
49	In	0.12	< 0.01	0.02
50	Sn	170	110	18
51	Sb	1.2	15	3.3
52	Te	0.01	< 0.01	< 0.01
53	I	< 0.01※1	< 0.01※1	< 0.01※1
54	Xe			
55	Cs	< 0.01※1	< 0.01※1	< 0.01※1
56	Ba	< 0.01	< 0.01	< 0.01
57	La	< 0.01	< 0.01	< 0.01
58	Ce	< 0.01	< 0.01	< 0.01
59	Pr	< 0.01	< 0.01	< 0.01
60	Nd	< 0.01	< 0.01	< 0.01
61	Pm			
62	Sm	< 0.01	< 0.01	< 0.01
63	Eu	< 0.01	< 0.01	< 0.01
64	Gd	< 0.01	< 0.01	< 0.01
65	Tb	< 0.01	< 0.01	< 0.01
66	Dy	< 0.01	< 0.01	< 0.01
67	Ho	< 0.01	< 0.01	< 0.01
68	Er	< 0.01	< 0.01	< 0.01
69	Tm	< 0.01	< 0.01	< 0.01
70	Yb	< 0.01	< 0.01	< 0.01
71	Lu	< 0.01	< 0.01	< 0.01
72	Hf	< 0.01	< 0.01	< 0.01
73	Ta	< 0.01※2	< 1※2	< 5※2
74	W	< 0.01	240	60
75	Re	< 0.01	0.54	0.17
76	Os	< 0.01※1	0.06※1	0.05※1
77	Ir	< 0.01	0.1	0.06
78	Pt	< 0.01	0.37	0.16
79	Au	0.01	0.06	0.02
80	Hg	< 0.01	< 0.01	< 0.01
81	Tl	2.6	< 0.01	< 0.01
82	Pb	Matrix	0.06	0.31
83	Bi	13	< 0.01	< 0.01
84	Po			
85	At			
86	Rn			
87	Fr			
88	Ra			
89	Ac			
90	Th	< 0.005	< 0.005	< 0.005
91	Pa			
92	U	< 0.005	< 0.005	< 0.005

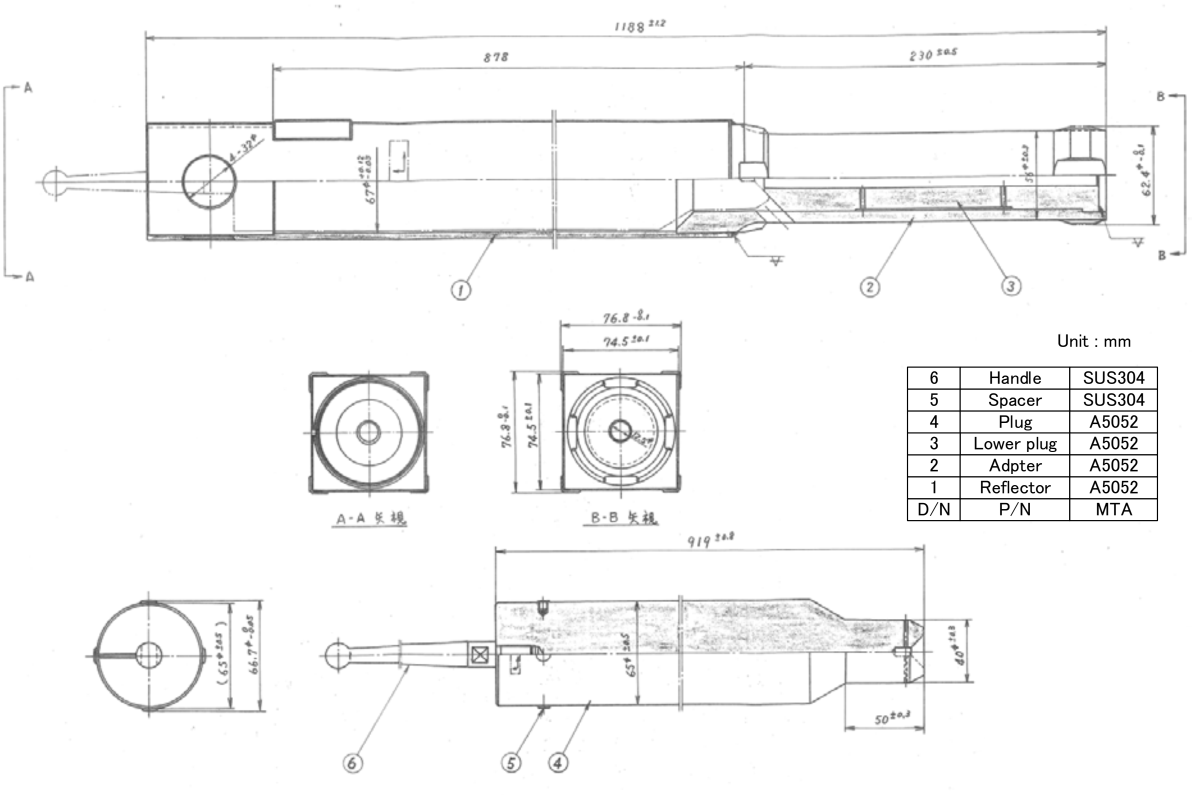
※1 : GD-MS is RSF (Relative Sensitivity Factors) converted concentration expressed with Pb or Fe+Cr+Ni as 100%.
For elements whose RSF is unknown, analysis values are calculated using ionic strength.

※2 : Regarding Ta, the analysis value includes contamination from discharge cells, etc.



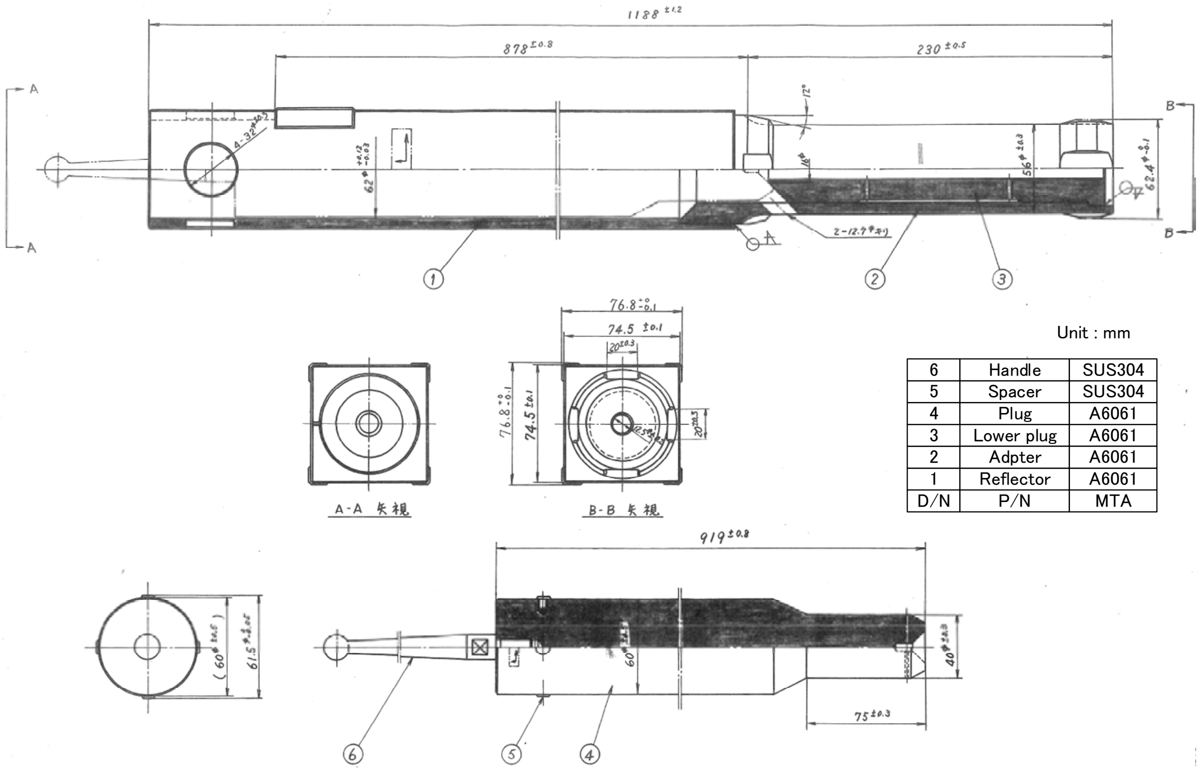
5	Spacer	SUS304
4	Upper plug	A6063
3	Tavel-pin	SUS304
2	Lower plug	A6063
1	Reflector	A6063
D/N	P/N	MTA

Fig. 1 Outline diagram of the aluminum reflector and aluminum plug (C-type) (from drawing and specification)



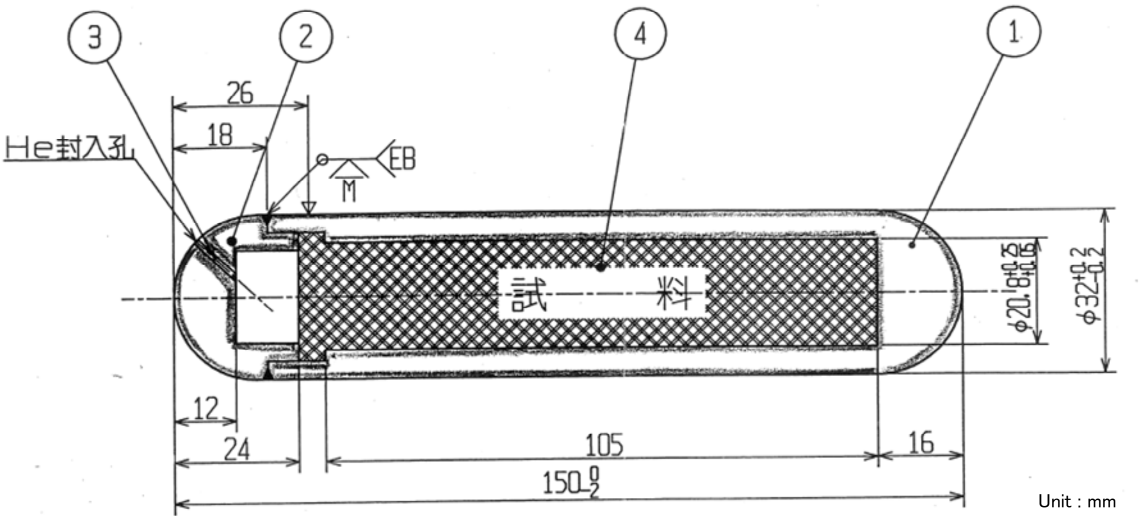
6	Handle	SUS304
5	Spacer	SUS304
4	Plug	A5052
3	Lower plug	A5052
2	Adpter	A5052
1	Reflector	A5052
D/N	P/N	MTA

Fig. 2 Outline diagram of the aluminum reflector and aluminum plug (E-type) (from literature[13])



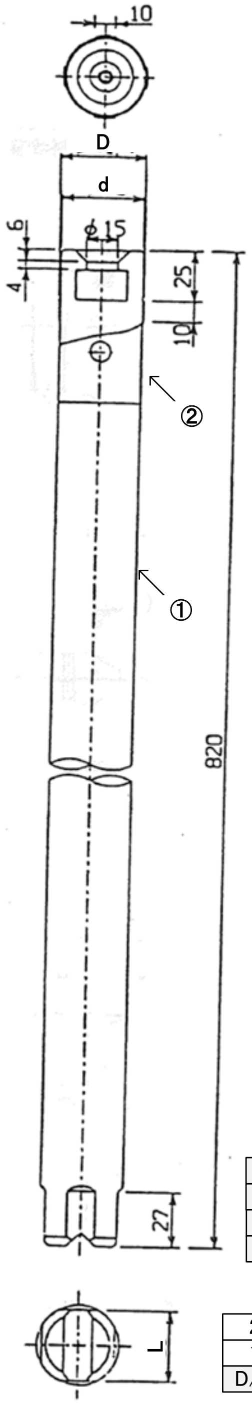
D/N	P/N	MTA
6	Handle	SUS304
5	Spacer	SUS304
4	Plug	A6061
3	Lower plug	A6061
2	Adpter	A6061
1	Reflector	A6061

Fig. 3 Outline diagram of the aluminum reflector and aluminum plug (F-type) (from literature[14])



D/N	P/N	MTA
4	Specimen	–
3	TAper-pin	A1050
2	Upper plug	A1050
1	Out pipe	A1050

Fig. 4 Outline diagram of the hydraulic rabbit (from drawing and specification)



Unit : mm

	ϕ32	ϕ38	ϕ40
D	ϕ32.5	ϕ38.5	ϕ41.7
d	ϕ30	ϕ36	ϕ40
L	26	30	35

2	Middle plug handle	A6061
1	Middle plug	Be
D/N	P/N	MTA

Fig. 5　Outline diagram of the beryllium plug (from drawing and specification)

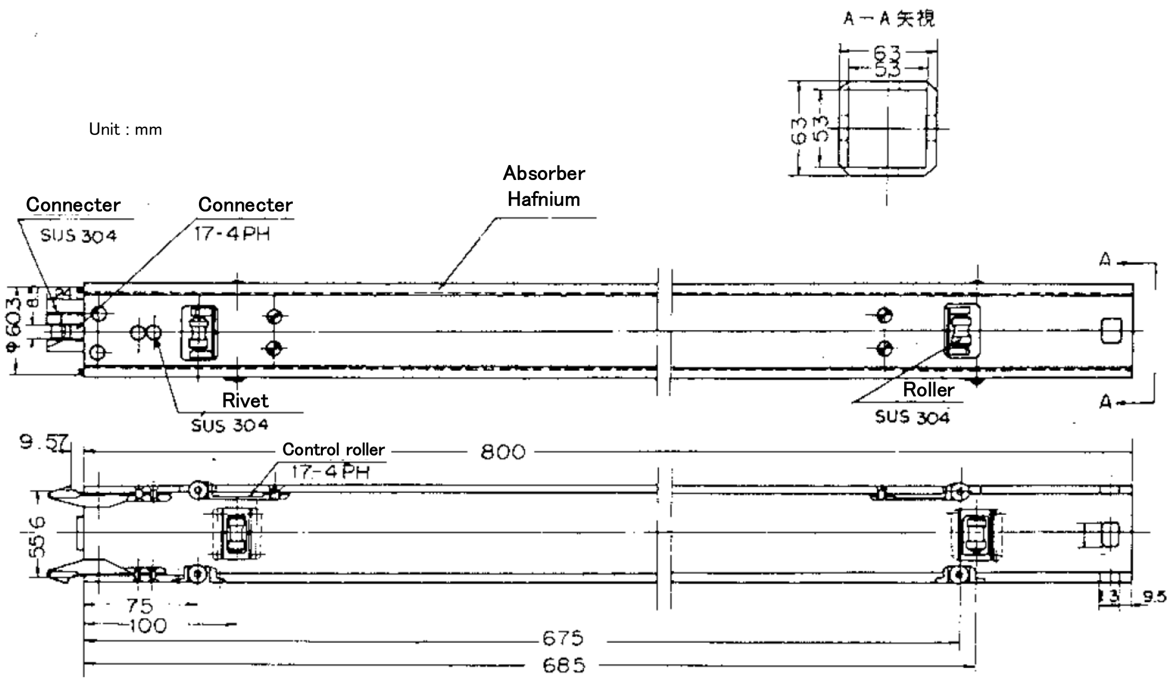


Fig. 6　Outline diagram of the control rod
(from literature[15])

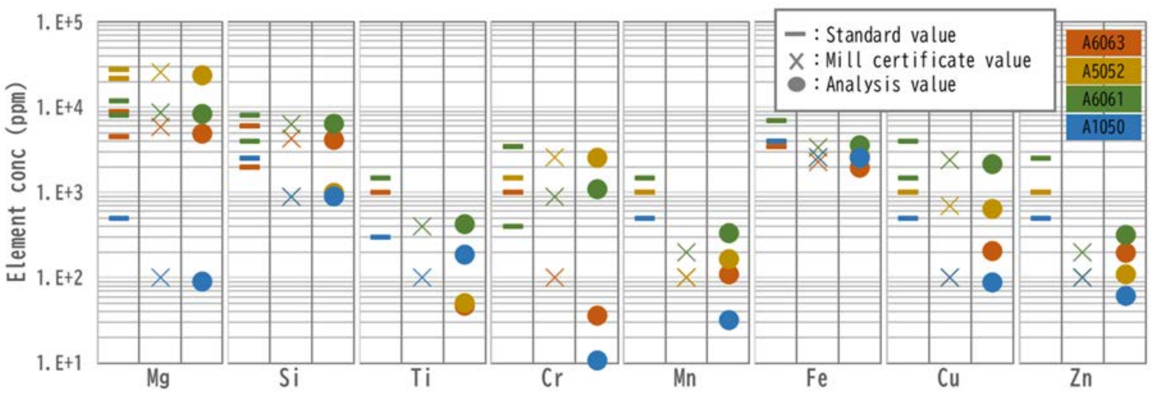


Fig. 7　Analysis results and mill sheet values for main component elements of aluminum alloys

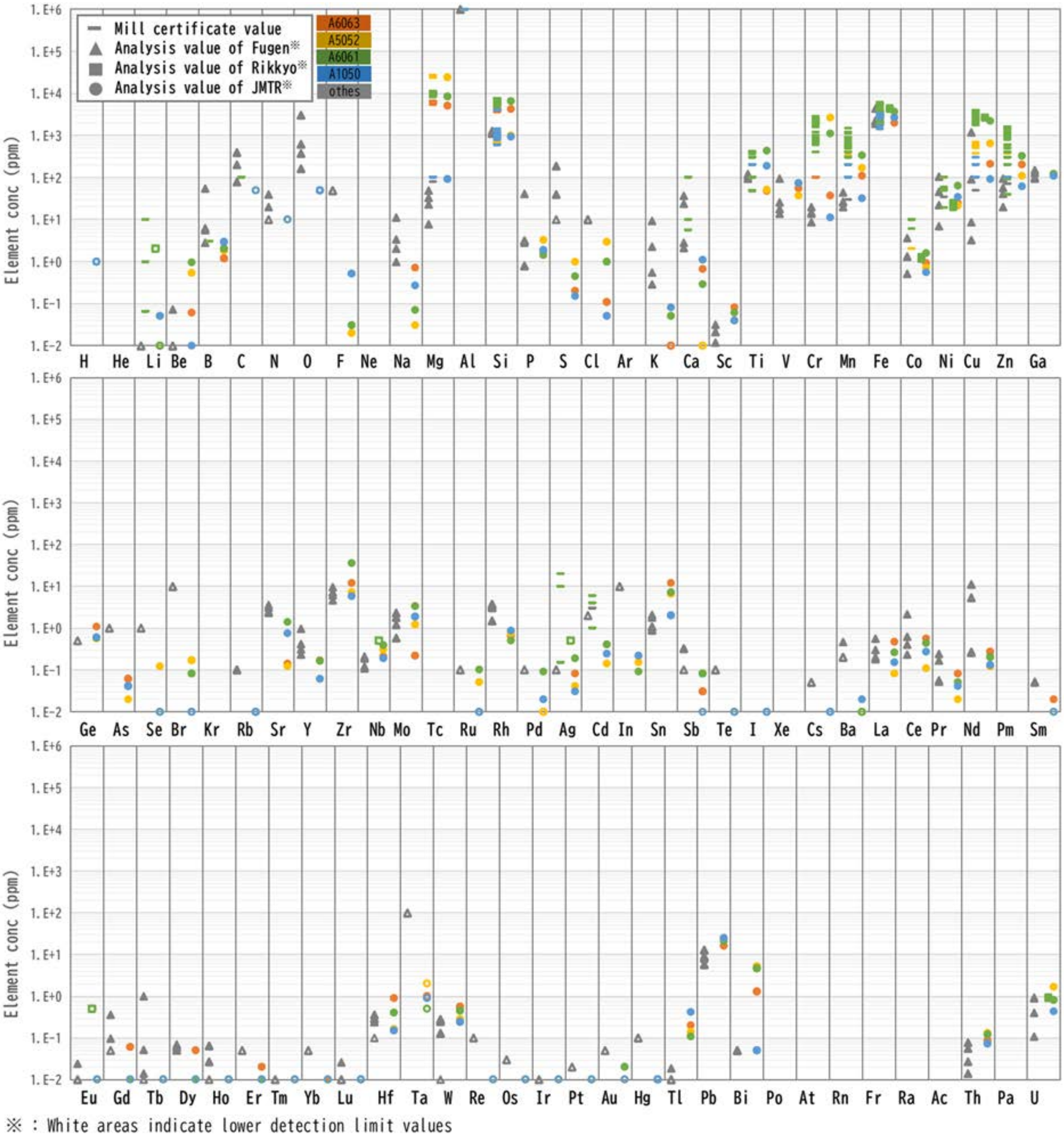


Fig. 8 Plot of all elemental composition data including analytical data from other facilities of the aluminum alloy[3)4)5)12)]

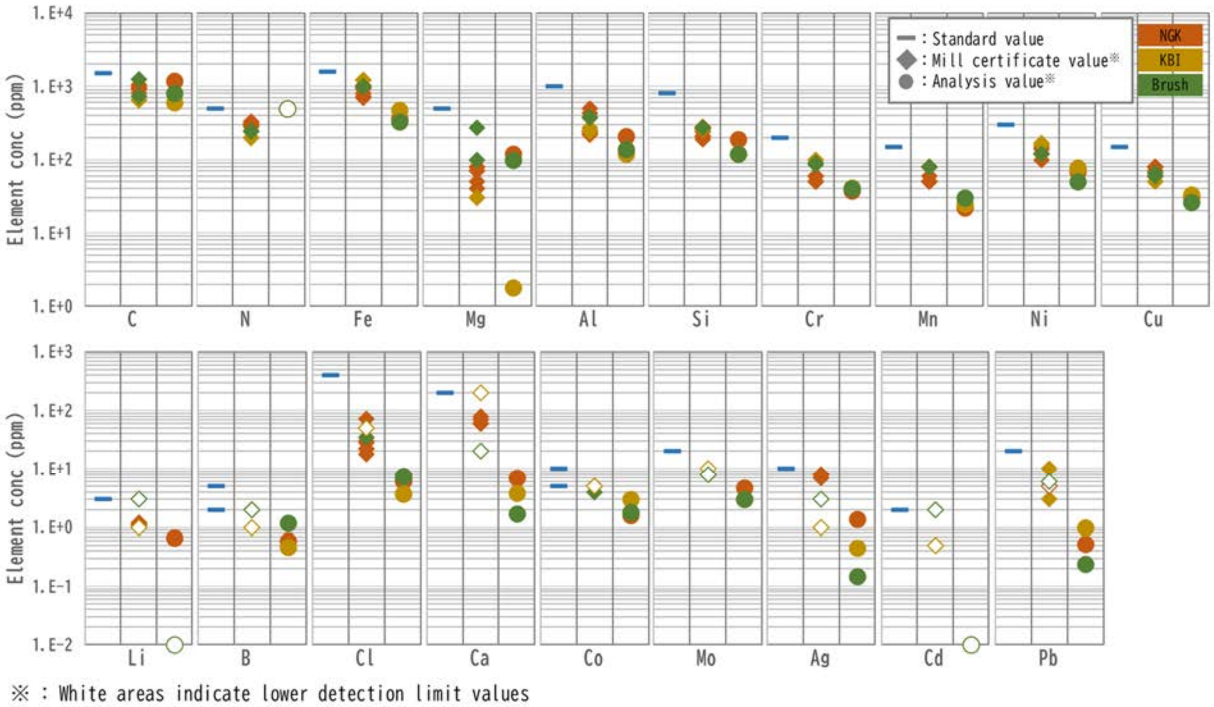
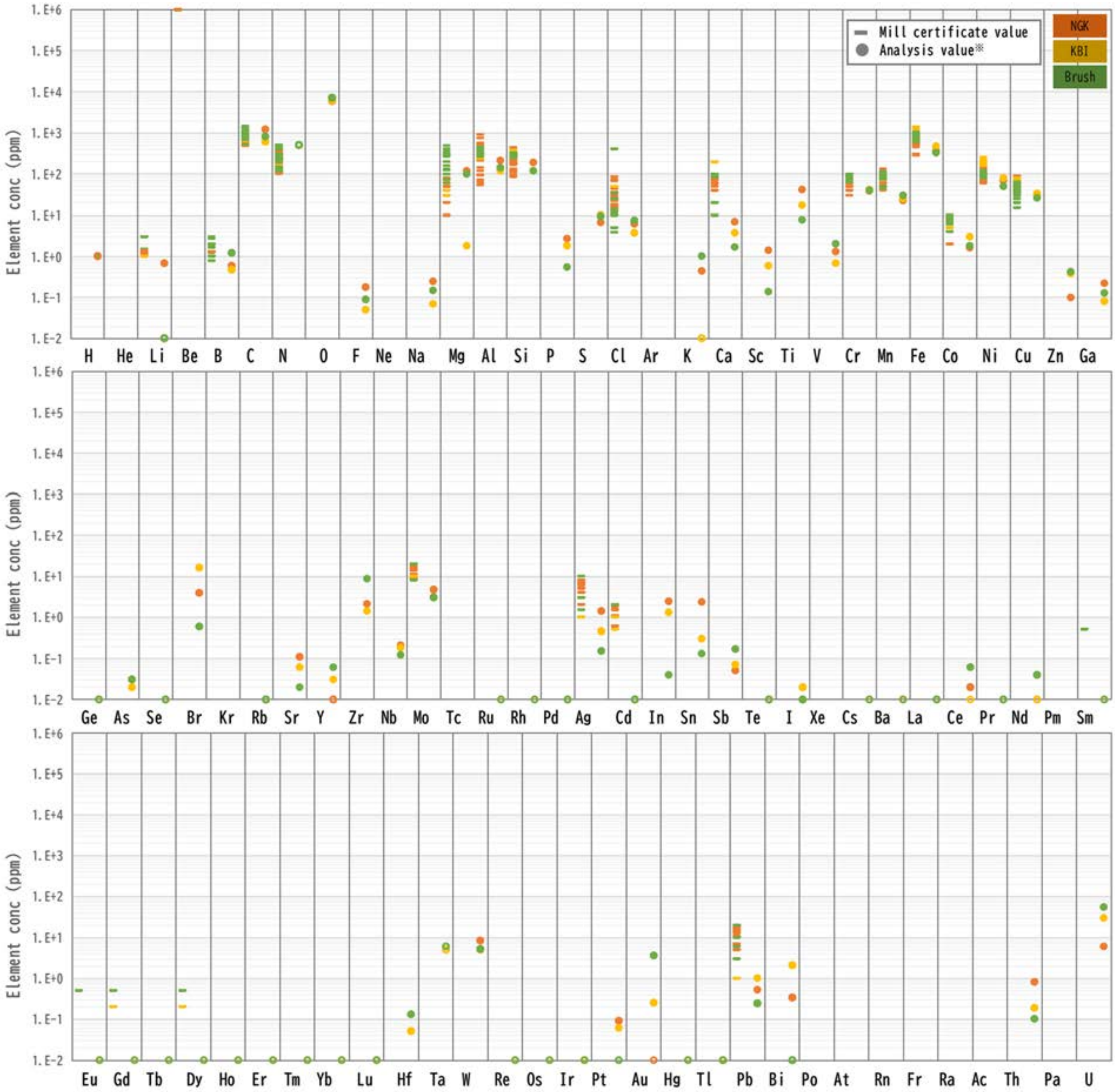


Fig. 9 Analysis results and mill sheet values for main component elements of beryllium



※ : White areas indicate lower detection limit values

Fig. 10　Plot of all elemental composition data of the beryllium

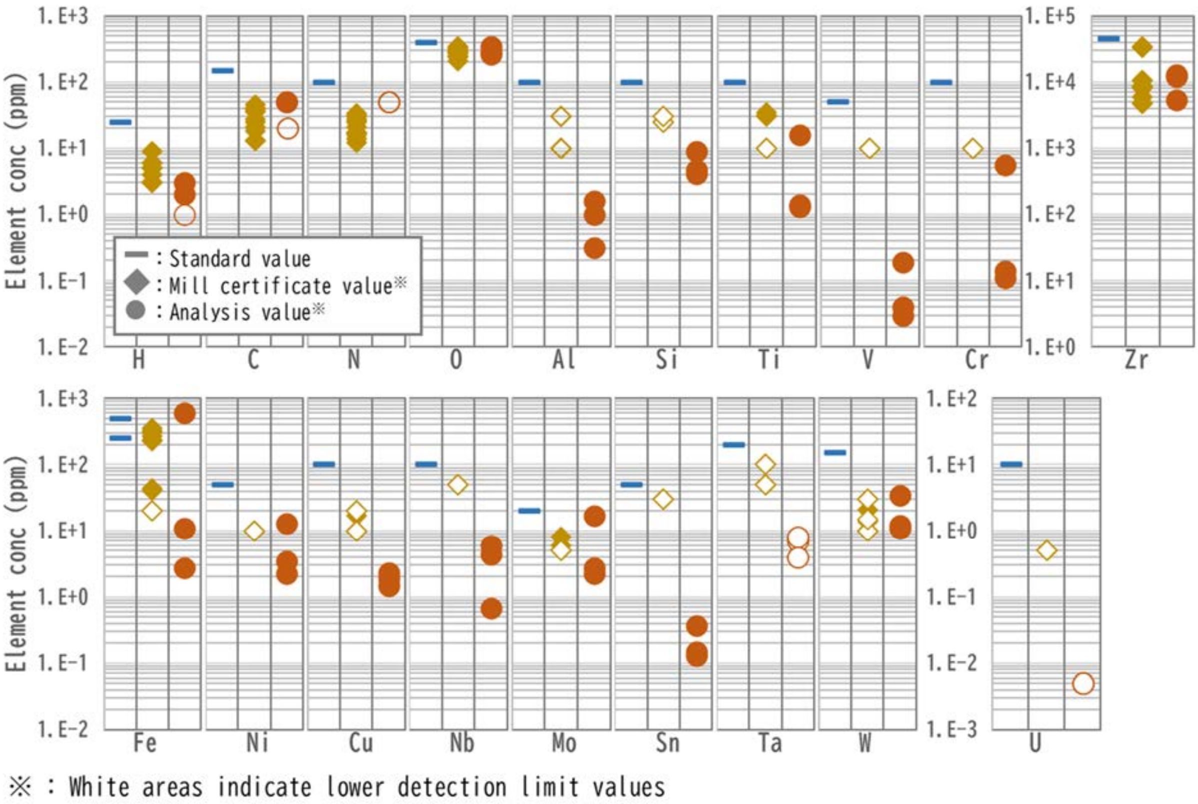


Fig. 11 Analysis results and mill sheet values for main component elements of hafnium

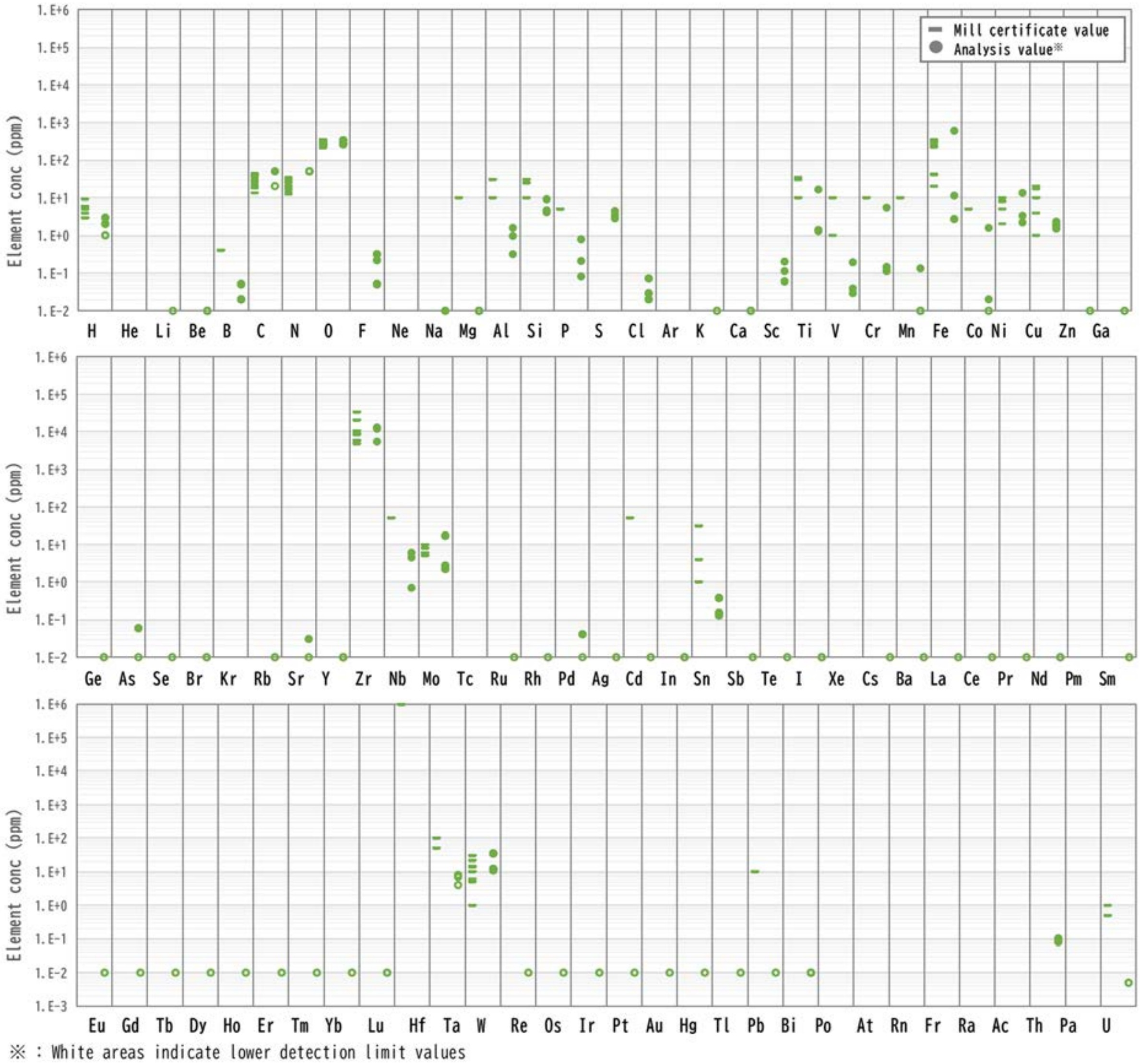


Fig. 12 Plot of all elemental composition data of the hafnium

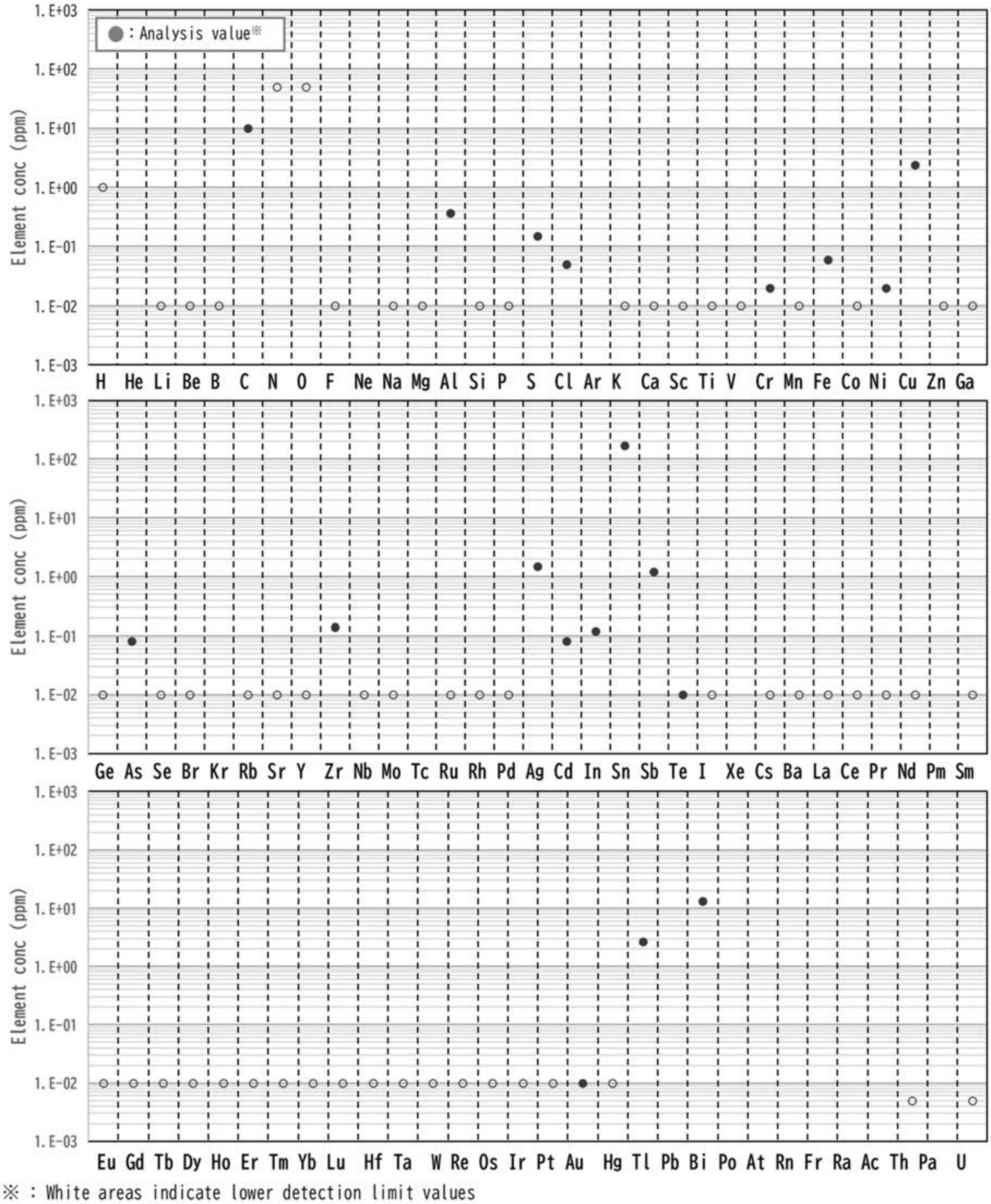


Fig. 13 Plot of all elemental composition data of the lead

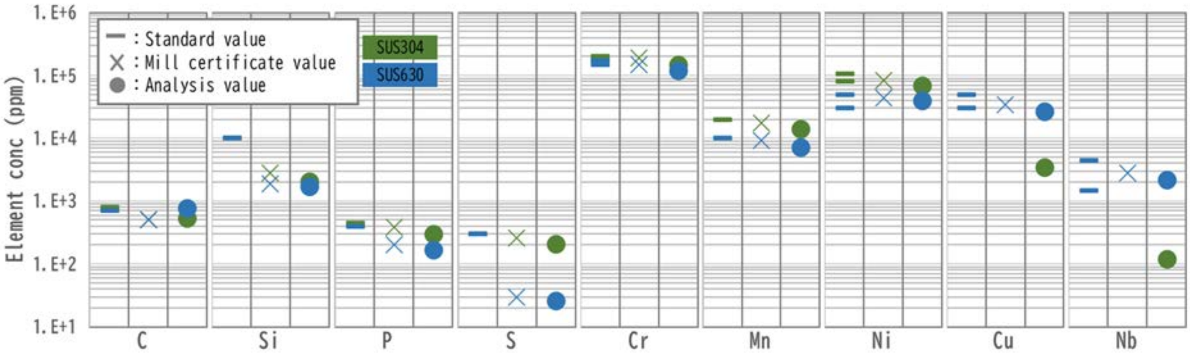
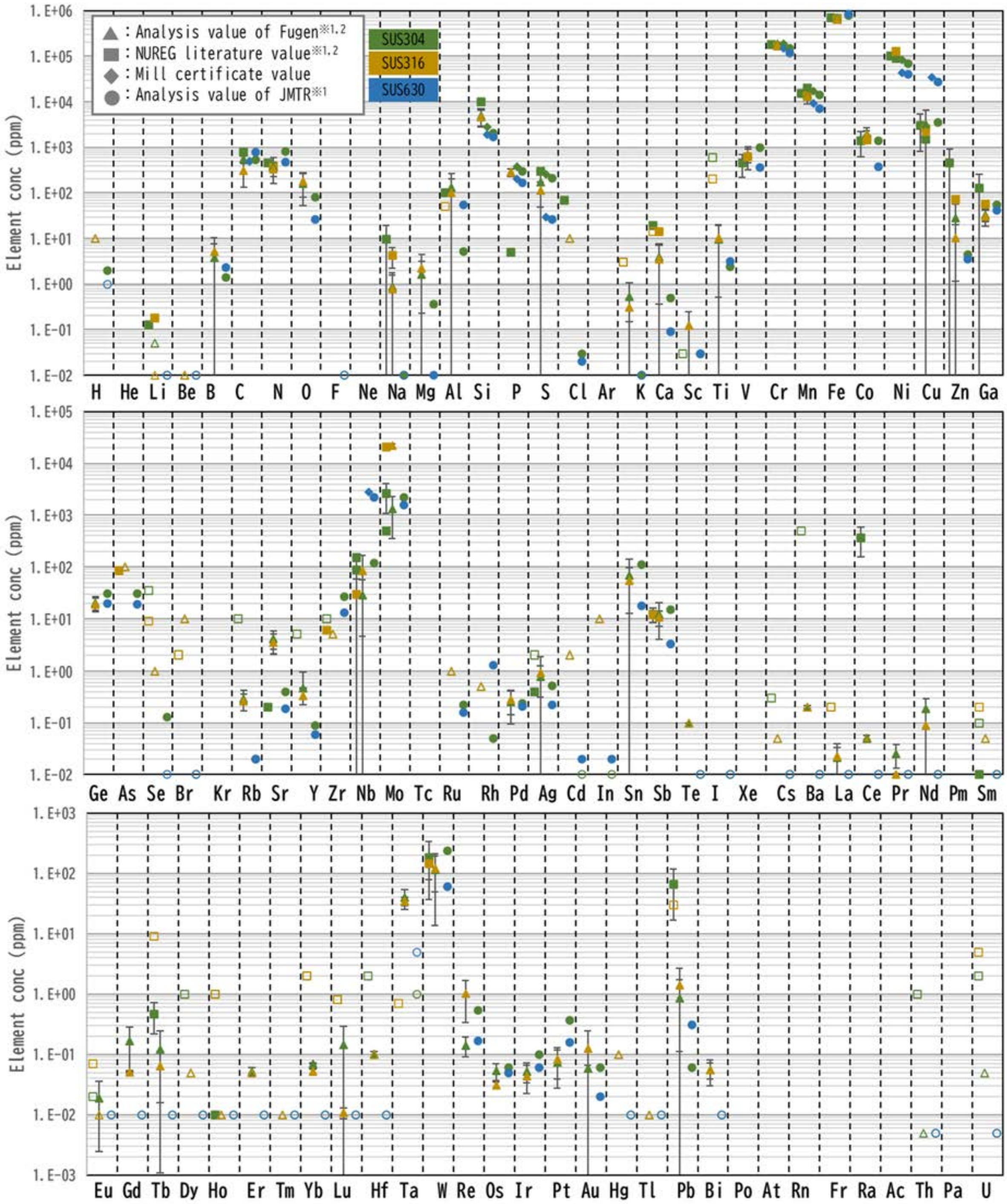


Fig. 14 Analysis results and mill sheet values for main component elements of stainless steel



※1 : White areas indicate lower detection limit values

※2 : Detected value represents average value of analyzed values and error bar represents its standard deviation

Fig. 15 Plot of all elemental composition data of the stainless steel[1)2)3)4)]

Sample No.1 Aluminum reflector 1 hole C type 42 φ FR (C007)	Sample No.2 Aluminum plug 1 hole E type 67 φ FR (E005)	Sample No.3 Aluminum plug 1 hole F type 62 φ FR (F04F)
		

Photo 1　External appearance of the aluminum alloy (Samples No.1-3)

Sample No.4 Hydraulic rabbit (RM-4897)


Photo 2　External appearance of the aluminum alloy (Sample No.4)

Sample No.5 Beryllium plug ϕ 38Be for Be-frame (No.21)	Sample No.6 Beryllium plug ϕ 38Be for Be-frame (No.52)	Sample No.7 Beryllium plug ϕ 42Be for Be-frame (No.79)
		

Photo 3　External appearance of the beryllium (Samples No.5-7)

Sample No.8 Control rod (Hf-24)	Sample No.9 Control rod (Hf-27)	Sample No.10 Preliminary welding test piece of control rod
		

Photo 4　External appearance of the hafnium (Samples No.8-10)

Sample No.11 Lead shielding block


Photo 5　External appearance of the lead (Sample No.11)

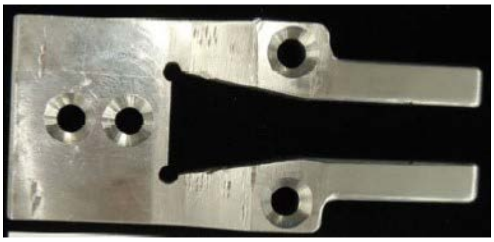
Sample No.12 stainless steel (SUS304)	Sample No.13 stainless steel (SUS630)
	

Photo 6　External appearance of the stainless steel (Samples No.12-13)