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기 술 보 고 서

Fabrication of a CANFLEX-RU Designed Bundle for Power Ramp Irradiation Test in NRU

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제 출 문

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본 보고서를 중수로용 순환우라늄 핵연료 기술개발 과제의 "Fabrication of a CANFLEX-RU Designed Bundle for Power Ramp Irradiation Test in NRU" 기술보고서로 제출합니다.

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1. Introduction

The BDL-443 CANFLEX-RU bundle AKW was fabricated at Korea Atomic Energy Research Institute (KAERI) for power ramp irradiation testing in NRU reactor. The bundle was fabricated with IDR and ADU fuel pellets in adjacent elements and contains fuel pellets enriched to 1.65 wt% ^{235}U in the outer and intermediate rings and also contains pellets enriched to 2.00 wt% ^{235}U in the inner ring. This bundle does not have a center element to allow for insertion on a hanger bar.

KAERI produced the IDR pellets with the IDR-source UO_2 powder supplied by BNFL. ADU pellets were fabricated and supplied by AECL. Bundle kits (Zircaloy-4 end plates, end plugs, and sheaths with brazed appendages) manufactured at KAERI earlier in 1996 were used for the fabrication of the bundle[1].

Brief history of the bundle fabrication is summarized as follows:

Apr. 1998	Receipt of IDR powder from BNFL
May-July 1998	Fabrication of IDR pellets
Jan. 1999	Receipt of ADU pellets from AECL
Jan.-Feb. 1999	Fabrication of the Bundle
Mar.-Aug. 1999	Application for USDOE approval for sending ADU pellets back to AECL
Sep. 1999	Shipping of the bundle to AECL
Sep. 1999	Issuance of the fabrication report KF-FR-99-01 Rev.0[2]

All fabrication works of the KAERI bundle were performed in collaboration with the CANFLEX project team of KEPCO Nuclear Fuel Company Ltd.

2. Quality Assurance Plan

Provisions in the following quality document were implemented as appropriately for the fabrication of the CANFLEX bundle.

- Quality Assurance Manual for HWR Fuel Project[3]

This document outlines the responsibilities and procedures for the quality assurance of the CANFLEX bundle. Verification of end-closure welding and qualification of bundle assembly welding was conducted before the start of fabrication. The fabrication activities were carried out using established and approved manufacturing operating procedures and inspection procedures.

3. Materials

3.1 IDR Fuel Pellets

3.1.1 Fabrication

Two IDR-derived powders (natural and 2.67% U-235) were supplied by British Nuclear Fuels plc(BNFL). Analysis results for the starting uranium dioxide powders are given in Appendix 1. The two powders were blended to produce 1.65% and 2.0% IDR-source UO_2 powders and were fabricated into the pellets of two different diameters.

3.1.2 Characterization

Pellets for inspection were chosen at random following centerless grinding. A summary of the characteristics measured, methods used and accuracy of the methods is given in Table 1. Analysis results are summarized in Table 2

Table 1 IDR Pellet Characterization Methods and their Associated Accuracy

Characteristic Measured	Method	Accuracy	Procedure
Chamfer Width	Stereo Microscope	0.02mm	QCI-163[4]
Diameter	Micrometer	0.001mm	"
Height	Digital Vernier Calipers	0.01mm	"
Surface Finish	Surface Roughness Device	0.05Ra	"
Mass	Balance	0.001g	QCI-111[5]
Dish Depth	Depth Micrometer	0.01mm	QCI-163
Density	Immersion	0.01g/cm^3	QCI-111

Table 2 IDR Pellet Characterization Summary (Average Value)

Fuel Type	Dish Depth (mm)	Chamfer Width (mm)	Surface Rough. (Ra)	Height (mm)	Diameter (mm)	Immer. Density (g/cm^3)	Mass (g)	Grain Size (μ m)
1.65%	0.19	.24	0.71	13.79	10.71	10.68	12.16	5.85
2.00%	0.24	.24	0.71	15.28	12.66	10.68	19.74	6.20
Accept. Criteria	0.011x ht. ± .07mm	0.25± 0.13mm	0.8μ m Ra Max.	L/D=1.4 Max.	10.715± 0.013 or 12.675± 0.013mm	10.60 g/cm3 ± 0.15	-	5-30 μ m

3.2 ADU fuel pellets

Two kinds of ADU pellets were supplied by AECL. The fabrication and characterization of ADU pellets are recorded in the relevant AECL fabrication report.

3.3 Zircaloy Hardware

Bundle kits (Zircaloy-4 end plates, end plugs, and sheaths with brazed appendages) manufactured at KAERI earlier in 1996 were used for this fabrication campaign. All the zircaloy hardware were visually inspected and cleaned by air blowing prior to use. The fabrication data for the Zircaloy hardware used for this campaign are provided in KAERI technical report KF-FR-97-01[1].

4. Special Processes

Two special processes, end-closure welding and bundle assembly welding, were used during this fabrication campaign. Both special processes were confirmed to be qualified prior to the start of fabrication of the CANFLEX bundle.

4.1 Verification of End-Closure Welding

The quality of the end-closure welding process is determined by destructive examination of representative weld samples. These weld samples were produced in a manner identical to the final product, i.e., with the same materials, using the same conditions and parameters as for production. *The following subsections list the results of end-closure PC weld process* verification.

4.1.1 Weld Rating

PC weld samples were sectioned and examined metallographically for weld soundness. The length of the weld line (minus any discontinuities) must be greater than the minimum tube wall thickness. This parameter, referred to as weld ratings, is reported as a percent of the minimum tube wall thickness. The end cap weld rating was defined in KAERI QCI (Quality Control Instruction) #731[6] as follows:

Weld Rating = (Total sound weld in zones +50% of internal upset) / Sheath thickness

The specified minimum is for a weld rating ≥ 100%. KAERI QCI #731 requires *the soundness of weld rating to be judged either as 'Accepted' or 'Rejected'.*
Three specimens for each type of fuel sheath were adopted for the qualification of the process even though large numbers of specimens were tested in advance to adjust the process. The following results were measured from end-closure PC weld samples:

a. Ø11.5mm: 3 sections tested; All accepted.
b. Ø13.5mm: 3 sections tested; All accepted

Therefore, the weld rating was acceptable for both diameters.

4.1.2 Peel Test

Peel testing consists of pulling the tube away from the end-cap on half sections of PC weld samples. The acceptance criterion is for failure to occur away from the weld.

a. Ø11.5 mm: 10 half sections tested,
Failure occurred away from the weld area; Accepted
b. Ø13.5 mm: 10 half sections tested,
Failure occurred away from the weld area; Accepted

4.2 Qualification of Bundle Assembly Welding

The strength of bundle assembly welds is shown through destructive testing of PC weld samples. Torque strengths of 49 specimens (thirty-nine 11.5mm PC and ten 11.5mm PC) tested during this campaign are presented in Table 3.

The relation between PC welds and actual end plate welds was presented in KAERI Process Qualification Report for the CANFLEX fuel assembly welding process, KF-TR-95-003 (Attachment 1) issued in May 18, 1995 and it specified control limit for PC welds torque strengths. The control limits were minimum 7.9 Nm and 6.3 Nm for 11.5mm and 13.5mm sheath, respectively. It means that the process cannot be qualified if any of the samples are not within the limit.

Table 3 shows that none of the values are below the control limits. Therefore, the assembly welding process is judged to be acceptable based on the control limit derived from the relation between PC welds and actual end plate welds.

Table 3 Result of Torque Strength Test

Type	Torque Strength					Average	Std. Dev.
Ø11.5mm	13	13.5	13.5	13.2	12.7	12.82Nm	0.68Nm
	12	12.7	12.1	12.6	13.5		
	11.7	12.5	12.1	11.6	12.3		
	12.4	12	12	11.3	13.4		
	12.5	13.5	13.2	13.7	13.2		
	12.2	13.7	13.4	13.7	13.2		
	13.6	12.2	12.7	12.6	13.2		
	13	13.5	14	13			
Ø13.5mm	7.8	7.5	8.3	8.2	7.9	8.37Nm	0.81Nm
	9.7	9.7	7.8	7.8	9		

5. Fabrication

5.1 In-Coming Inspection of ADU pellets supplied by AECL

Visual inspection for the ADU pellets supplied by AECL was performed. Defect pellets were segregated and prevented from use in fabrication.

5.2 CANLUB coating

The sheaths were CANLUB coated, cut to the finished length and weld-prep machined on each end in accordance with OI-608[7], OI-609-2[8] and OI-611-1[9]. Nine and six samples of 11.5mm and of 13.5mm CANLUB coated tube were taken and the thickness was measured. The measured values are presented in Table 4.

Table 4 CANLUB Thickness

Ø11.5 mm				Ø13.5mm			
Smpl #	Bottom	Middle	Top	Smpl #	Bottom	Middle	Top
1	11.1	12.1	3.4	1	8.4	11.9	4.8
2	11.6	11.7	5.3	2	7.7	6.7	4.3
3	11.4	12.6	5.5	3	5.7	6.1	5.0
4	11.9	14.4	8.7	4	6.3	6.0	4.0
5	11.5	12.2	5.3	5	5.3	6.6	3.9
6	9.8	12.3	4.3	6	6.0	5.6	2.6
7	10.2	10.7	4.5				
8	10.8	14.3	4.9				
9	9.7	12.0	5.3				
Average		9.5 μm		Average		6 μm	
Std. Dev.		3.4 μm		Std. Dev.		2 μm	

H-gas content in the filling gas was calculated using the ideal gas state equation shown below.

$$PV = nRT$$

P and T represent the pressure and the temperature in the fuel element and the void volume, V was calculated using average dimensions in fabrication data as in attachment 2. Void volumes of the fuel elements are 1,306mm^3 and 1,668mm^3 for the Ø11.5 and the Ø13.5 fuel element, respectively. The filling gas contains 10 PPM of H-gas at most as shown in attachment 3 and 80% of the void volume, at least, was filled with He-gas. The calculation showed that the amount of H-gas was negligible compared to those in the pellet or CANLUB.

H-gas content in the pellet was not measured during the fabrication of CANFLEX-RU designed KAERI bundle. Therefore, it was predicted based on the data (Attachment 4) measured during the mass production of CANDU fuels in the same fabrication process. Average amount of H-gas contained in the pellets is presented in Table 5 with its standard deviation.

In conclusion, total H-gas in the fuel element is 118.9 μg and is less than the H-gas limit of 600 μg as defined in QCI-722 [10].

Table 5. H-gas contents

Component	Average	Std. Deviation	Remarks
CANLUB	82.0 μg	24.5 μg	
Pellets	36.9 μg	19.0 μg	CANDU Data
Filling Gas	0.0 μg	-	
Total	118.9 μg		

5.2 Fuel Loading

All pellets were visually inspected during element loading. Pellet discs were cut from whole pellets and inserted second from the non-reference end pellet to achieve the specified stack length or the specified axial gaps. Details of the data obtained during fuel loading such as stack length, number of pellets etc. are listed in Table 6. Axial gap for each element was calculated based on the following formula.

$$\text{Axial Gap} = \text{Element length} - 2 \times \text{End-cap height} - \text{Stack length}$$

The end-cap height is taken by the average value which was calculated based on the fabrication data given in the attachments 16 and 17 of the fabrication report for the bundle kit[1]. The calculated L and S type end-cap heights were 4.075 mm and 5.065 mm, respectively. All the values of the axial gap are within the design requirement (1mm ≤ clearance ≤ 3mm) as defined in the drawing, CANFLEX-37000-1-1-GA-E, Rev.5 [11].

Diametral clearance was calculated using following formula.

$$\text{Diametral clearance} = \text{Sheath I.D} - \text{Pellet O.D}$$

Only average values are available for sheath I.D and pellet O.D. Therefore average diametral clearances were calculated and presented in Table 7 for 11.5 mm and 13.5 mm fuel sheath, respectively.

Table 6 Fuel loading data for bundle AKW

El #	Powder Type	Number of Pellet	Stack Length (mm)	Element Length (mm)	Axial Gap	UO2 (g)	Enr.U(g)	U235(g)
1	IDR	34	480.83	492.84	1.88	452	398.44	6.57
2	ADU	40	481.50	493.12	1.49	450	396.69	6.51
3	IDR	34	480.90	492.88	1.85	451	397.56	6.56
4	ADU	39	480.90	492.86	1.83	450	396.69	6.51
5	IDR	36	480.80	492.92	1.99	451	397.56	6.56
6	ADU	40	481.18	492.85	1.54	450	396.69	6.51
7	IDR	36	480.80	492.83	1.9	452	398.44	6.57
8	ADU	40	481.68	492.90	1.09	450	396.69	6.51
9	IDR	36	480.90	492.98	1.95	451	397.56	6.56
10	ADU	39	481.32	492.91	1.46	450	396.69	6.51
11	IDR	36	480.70	493.11	2.28	451	397.56	6.56
12	ADU	39	481.22	492.95	1.6	451	397.56	6.52
13	IDR	36	480.60	492.88	2.15	451	397.56	6.56
14	ADU	39	480.64	492.83	2.06	450	396.69	6.51
15	IDR	36	480.90	492.89	1.86	451	397.56	6.56
16	ADU	40	481.66	493.11	1.32	451	397.56	6.52
17	IDR	34	480.90	492.92	1.89	451	397.56	6.56
18	ADU	39	481.34	492.87	1.4	450	396.69	6.51
19	IDR	35	480.80	492.90	1.97	452	398.44	6.57
20	ADU	39	480.82	492.95	2	450	396.69	6.51
21	IDR	35	480.80	492.91	1.98	453	399.32	6.59
22	ADU	39	481.38	492.81	1.3	450	396.69	6.51
23	IDR	36	481.05	492.85	1.67	451	397.56	6.56
24	ADU	39	480.82	492.69	1.74	449	395.81	6.49
25	IDR	34	480.90	493.11	2.08	451	397.56	6.56
26	ADU	38	480.52	492.71	2.06	451	397.56	6.52
27	IDR	35	480.80	492.98	2.05	451	397.56	6.56
28	ADU	39	480.92	492.67	1.62	450	396.69	6.51
29	IDR	35	480.90	492.90	1.87	451	397.56	6.56
30	ADU	39	481.28	492.76	1.35	449	395.81	6.49
31	IDR	35	480.90	492.92	1.89	451	397.56	6.56
32	ADU	39	480.48	492.80	2.19	450	396.69	6.51
33	IDR	35	481.10	492.84	1.61	451	397.56	6.56
34	ADU	39	480.56	492.67	1.98	450	396.69	6.51
35	IDR	34	480.90	492.98	1.95	451	397.56	6.56
36	ADU	35	482.80	492.69	1.74	646	569.58	11.28
37	IDR	31	482.62	492.96	2.19	637	561.68	11.23
38	ADU	35	482.78	492.81	1.88	646	569.58	11.28
39	IDR	32	482.72	492.78	1.91	638	562.56	11.25
40	ADU	35	483.30	492.69	1.24	646	569.58	11.28
41	IDR	31	482.50	492.75	2.1	639	563.43	11.27
42	ADU	31	482.52	492.55	1.88	638	562.56	11.14
Ave11.5	-	37.08	480.96	492.88	1.92		0.00	-
Ave13.5	-	32.50	482.74	492.77	1.81		0.00	-
SUM	-	-	-	-		20264.5	17864	307.48

Table 7 Diametral clearance

Type	Sheath I.D	Pellet O.D	Diametral Clearance
Ø11.5mm sheath	10.786 mm	10.71 mm	0.076 mm
Ø13.5mm sheath	12.735 mm	12.66 mm	0.075 mm

The average value of sheath I.D was given in the attachment 3 and 4 of the fabrication report for the bundle kit, KF-FR-97-01 Rev.0[1]. The average value of pellet O.D was given in the table 2 of the fabrication report, KF-FR-99-01 Rev.0[2]. The clearance values are within the design requirement (0.05mm ≤ clearance ≤ 0.13mm) as defined in the drawing, CANFLEX-37000-1-1-GA-E, Rev.5.

5.3 Element End-Closure Welding

The fuel elements were fabricated by welding the first end cap and the second end cap to the tube according to the manufacturing operating instructions for end-closure welding[12]. Qualification of end-closure welding for the two CANFLEX end-cap angles and diameters was conducted prior to the start of the campaign (See section 4.1).

5.4 Weld-flash Removal

The weld flash from the end-closure operation was removed on a low-speed lathe setup. Each element was checked against the specifications; no undercutting was observed, by visual examination, and the end-cap diameter was checked to be within specifications by micrometer.

5.5 Helium Leak Testing

All welded elements were subjected to helium leak testing prior to bundle assembly welding according to the manufacturing operating instruction for helium leak testing [13]. The acceptance criteria is no indication above 10^{-7} cm^3/s leak rate. No leaks were detected at the $5x10^{-8}$ cm^3/s detection level and therefore the results were acceptable.

5.6 Assembly welding of Fuel Bundle

The process was qualified briefly by measuring the break-torques of end-closure welds for two endplate test specimens according to the appropriate sections of the operating instruction for the bundle assembly welding[14]. Qualification of bundle assembly was conducted prior to the start of the campaign (See section 4.2).

Each element was visually inspected, as they were loaded into the assembly jig. Due to the different assembly weld upset, the two different element diameters were fabricated to slightly different length to ensure end-plate flatness. For bundle assembly, the reference-end end-plate was welded first, starting with the small diameter (outer and intermediate rings); then proceeding with the larger diameter elements. The bundle was then inverted and the non-reference end-plate welded, starting with the central and inner ring (larger diameter) elements, then proceeding with the outer ring (smaller diameter) elements.

5.7 Element Leak Test for the Assembled Bundle

Element leak test was conducted for the completed bundle after assembly welding according to the Manufacturing Operating Instructions for Helium Leak Testing. No leaks were detected at the 5×10^{-8} cm^3/sec detection level.

5.8 Kinked-Tube Test

The kinked-tube test was performed and the bundle freely passed through the kinked-tube gauge under its own weight.

6. Nonconformance

No nonconformance was reported during this campaign.

7. Conclusion

The CANFLEX bundle was fabricated successfully at KAERI according to the QA provisions specified in references and as per relevant KAERI drawings and technical specification. The fabricated bundle will be used for power ramp irradiation testing in NRU reactor.

This report covers the fabrication activities performed at KAERI. Fabrication processes performed at AECL including fabrication of ADU pellets will be documented in a separate report.

8. References

[1] Moon-Sung Cho, "Fabrication Report – CANFLEX Bundle Kit for Irradiation Test in NRU", KAERI Technical Report KF-FR-97-01 Rev.0, July 19, 1997.

[2] Moon-Sung Cho, "Fabrication Report – Fabrication of CANFLEX-RU designed Bundle for Power Ramp Irradiation Test in NRU", KAERI Technical Report KF-FR-99-01 Rev.0, September 21, 1999.

[3] "The Quality Assurance Manual for HWR Projects", KAERI, QAP May 1993

[4] "Quality Control Instruction – Inspection of UO_2 Pellet Dimension and Surface", KAERI, QCI-163 Rev.2, June 18, 1996.

[5] "Quality Control Instruction – Inspection of UO_2 Pellet Mass and Density", KAERI, QCI-111 Rev.8, February 1, 1994.

[6] "Quality Control Instruction – Inspection of End-cap welding", KAERI, QCI-731 Rev.7, August 1, 1996.

[7] "Operation Instruction – CANLUB Coating", KAERI, OI-608 Rev.10, July 13, 1996.

[8] "Operation Instruction – Baking", KAERI, OI-609-2 Rev.7, June 19, 1996.

[9] "Operation Instruction – Weld-prep Machining", KAERI, OI-611-1 Rev.5, March 3, 1992.

[10] "Quality Control Instruction – Analysis of H-gas content in fuel element," QCI-727 Rev.3, KAERI, August 28, 1996.

[11] Fuel bundle design drawing, "Joint AECL-KAERI CANFLEX 43 element bundle (CANDU-6) reference drawing," CANFLEX-37000-1-1-GA-E, Rev.5, KAERI/AECL, October 7, 1998.

[12] "Operation Instruction – Element End-closure Welding", KAERI, OI-703-1 Rev.9, May 17, 1996.

[13] "Operation Instruction – Helium Leak Testing", KAERI, OI-725 Rev.1, March 5, 1996.

[14] "Operation Instruction – Bundle Assembly Welding", KAERI, OI-804-1 Rev.7, June 13, 1995.

Attachment 1. Process Qualification Report

부록 2. 개량형 핵연료 다발 용접 공정의 공정자격화 시험결과

KAERI HWR FUEL DIV.	공 정 자 격 승 인 보 고 서 PROCESS QUALIFICATION REPORT		
	문서번호 Doc. No. KF-TR-95-003	개정번호 Rev. No.	날 자 Date 95. 5. 18

제 목 Subject CANFLEX fuel assembly welding

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PE 0306 A4 (297 x 210)

1. Scope

This report summarizes the process qualification of MKIV CANFLEX fuel assembly welding with EPW-2 welding machine.

2. References

The acceptance criteria, qualification procedures and welding operation, inspection instructions are outlined in the following documents.

- CANFLEX-TS-3700-001-P Product specification of CANFLEX fuel assembly
- KAERI WP-80 Process specification of CANDU fuel assembly welding
- KAERI OI-804 Operation instruction of CANDU fuel assembly welding
- KAERI QCI-861 Dimensional inspection instruction of CANDU fuel assembly
- KAERI QCI-841 Inspection instruction of weld torque strength

3. Qualification Procedure

- Process simulation specimen (PM set #1), 43 end caps were welded on MKIV end plate, was prepared and weld strengths were measured in accordance with QCI-841.
- 43 fuel rods containing UO_2 pellets in graphite coated fuel sheaths were assembled into CANFLEX MKIV fuel bundle as per OI-804. The visual and dimensional integrity of the fuel bundle were inspected in accordanced with QCI-861. The torque strengths of end plate welds were measured.
- Just after the assembly welding of test bundle, another process simulation specimens (PM set #2) was prepared and weld strengths were measured.

4. Qualification results

- Attached bundle inspection report shows inspection results of test bundle. The test bundle satified all the requirements except end plate height "E" dimension which was satified by filing of end plate.
- Table 1 shows the results of weld torque strengths of fuel bundle. The lowest weld strength was 8.2 N-m for outer-elements and 4.8 N-m for inner-elements. All the torque strengths in table 1 exceed the required torque strength i.e., 6.8 N-m for outer-elements and 4.6 N-m for inner-elements. In addition, these are satisfied with 95% confidence level as follws ;

$$\overline{X}_{outer} - 1.645\,6_{outer} = 8.6\ N\text{-}m > 6.8\ N\text{-}m$$

$$\overline{X}_{inner} - 1.645\,6_{inner} = 5.2\ N\text{-}m > 4.6\ N\text{-}m$$

Where $\overline{X}$: *Average torque strength*

6 : *Standard deviation*

- Table 2 shows the torque strengths for two set of process simulation specimens to correlate process simulation welds with actual fuel assembly welds. The control limit evaluated by statistical treatment of table 1 and table 2 is shown in table 3.

5. Conclusion

The torque strengths of the fuel bundle were higher than the required minimum of 6.8 N-m for outer-elements and 4.6 N-m for inner-elements with 95% confidence level. The external view and all the dimensional inspection items but end plate height were satisfied. "E" dimension could be satisfied by filing end plate welds. From these qualification results, it is found that fuel bundle welding process was qualified.

Table 1. Torque strengths of qualification fuel bundle

Location of outer element	Weld strength (N-m)		Location of inner element	Weld strength (N-m)	
	Monogram	Opposite		Monogram	Opposite
1	10.0	8.2	22	7.2	5.2
2	10.0	9.8	23	6.2	7.5
3	9.4	9.5	24	7.2	5.2
4	9.6	8.7	25	6.5	7.0
5	9.6	8.7	26	7.2	4.8
6	9.7	9.2	27	6.5	7.7
7	9.7	8.5	28	7.2	5.0
8	10.5	10.2	29	6.6	7.4
9	9.7	10.2	30	6.5	5.4
10	9.8	8.5	31	6.4	7.2
11	10.1	10.2	32	7.0	5.4
12	9.4	10.0	33	6.5	7.6
13	10.0	8.5	34	7.2	5.2
14	10.2	10.0	35	6.2	7.2
15	9.5	10.2	36	6.0	5.4
16	10.0	8.7	37	7.5	6.4
17	10,0	10.2	38	6.6	6.1
18	9.4	10.2	39	6.8	6.4
19	10.2	8.5	40	5.8	6.0
20	10.0	10.2	41	7.0	6.2
21	9.0	9.8	42	7.2	6,6
			43	7.0	5.3

Table 2. Torque strengths of process simulation (PS) specimens in fuel bundle qualification welding

Location of outer element	Weld strength (N-m)		Location of inner element	Weld strength (N-m)	
	PS. Set#1	PS. Set#2		PS. Set#1	PS. Set#2
1	9.6	9.2	22	6.8	7.8
2	9.8	9.8	23	7.2	6.4
3	9.4	8.5	24	6.0	8.0
4	9.0	9.6	25	7.5	8.2
5	8.4	9.7	26	7.5	7.4
6	9.0	9.8	27	8.4	8.2
7	9.2	10.5	28	7.8	8.0
8	10.0	11.0	29	8.2	7.8
9	9.5	9.8	30	6.7	7.4
10	10.2	9.7	31	7.0	7.7
11	10.0	10.4	32	6.8	6.0
12	9.7	9.4	33	7.4	7.2
13	10.5	10.2	34	7.2	5.8
14	9.8	10.8	35	7.2	6.5
15	8.7	9.0	36	6.4	7.5
16	9.6	10.4	37	6.0	4.8
17	10.5	10.6	38	7.0	7.2
18	9.6	9.4	39	7.5	6.5
19	9.4	9.6	40	5.2	5.7
20	9.6	10.2	41	5.7	6.5
21	9.0	9.2	42	6.8	7.0
			43	6.6	6.7

Table 3. Evaluation of weld torque data of fuel bundle assembly welding

Average($\bar{X}$) & standard deviation (σ) / Location of fuel element / Experiment	$\bar{X}$ (N-m)		σ		$\bar{X}$-1.645σ	
	Outer	Inner	Outer	Inner	Outer	Inner
Process simulation Set #1	9.7	6.8	0.5	0.7	8.9	5.6
Fuel bundle qualification weld	9.6	6.5	0.6	0.8	8.6	5.2
Process simulation Set #2	10.0	6.7	0.6	0.8	9.0	5.4

※ Contol limit

outer element $6.8+|\bar{X}_{ps\ out}-\bar{X}_{bundle.out}|+1.645\sigma_{bundle.out}=7.9$

Inner element $4.5+|\bar{X}_{ps\ inn}-\bar{X}_{bundle.inn}|+1.645\sigma_{bundle.inn}=6.3$

Where, $\bar{X}_{ps\ out}=9.7$

$\bar{X}_{ps\ inn}=7.0$

BUNDLE INSPECTION REPORT

KAERI

Bundle No. : TEST

<table>
<tr><th>No.</th><th>Characteristics</th><th colspan="2">Monogram</th><th colspan="2">Opposite</th><th>Remark</th></tr>
<tr><td>1</td><td>End Cap Angle (72° ± 1°)</td><td colspan="2">OK</td><td colspan="2">OK</td><td></td></tr>
<tr><td>2</td><td>Visual Examination</td><td colspan="2">OK</td><td colspan="2">OK</td><td></td></tr>
<tr><td>3</td><td>End Plate Perpendicularity (1.80 MAX.)</td><td colspan="2">1.350</td><td colspan="2">1.386</td><td></td></tr>
<tr><td>4</td><td>End Plate Height (96.90 MAX.)</td><td colspan="2">97.386</td><td colspan="2">97.461 [1]</td><td></td></tr>
<tr><td>5</td><td>End Plate Waviness (0.56 MAX.)</td><td colspan="2">0.350</td><td colspan="2">0.290</td><td></td></tr>
<tr><td>6</td><td>End Cap Height (100.46 MIN.)</td><td colspan="2">100.514</td><td colspan="2">100.532</td><td></td></tr>
<tr><td>7</td><td>Droop (1.00 MIN.)</td><td colspan="2">1.268</td><td colspan="2">1.286</td><td></td></tr>
<tr><td>8</td><td>Spacer Alignment</td><td colspan="4">OK</td><td></td></tr>
<tr><td>9</td><td>Kink-Tube Gauge</td><td colspan="4">OK</td><td></td></tr>
<tr><td>10</td><td>Element Length Variation (0.56 MAX.)</td><td colspan="4">0.403</td><td></td></tr>
<tr><td>11</td><td>Rubber Band Rule (Button)</td><td colspan="4">OK</td><td></td></tr>
<tr><td rowspan="2">12</td><td rowspan="2">Bundle Diameter (102.50 MAX.)</td><td>Upper B.P</td><td colspan="2">Middle B.P</td><td>Lower B.P</td><td rowspan="2"></td></tr>
<tr><td>102.07</td><td colspan="2">102.08</td><td>102.08</td></tr>
<tr><td>13</td><td>Bundle Length (495.30 ± 0.75)</td><td colspan="4">495.90</td><td></td></tr>
</table>

Note : [1] "E" dimension of as-welded fuel bundle is a little higher than the specification. That can be satisfied by filing end plate welds.

Inspected by :

Reviewed by :

Attachment 2. Calculation of Element Void Volume

KAERI

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KAERI-CANFLEX-CHO-00-005
June 16, 2000

To: H.C. Suk
Cc:
From: M.S. Cho

Calculation of Element Void Volume for CANFLEX Bundle AKW

In this memo, element void volumes of CANFLEX bundle AKW were calculated for use in a standard post-irradiation performance assessment and also to ensure that there are no unusual features that may affect power-ramp performance.

1. Void Volume of the ∅11.5 Fuel Element

a. Pellet Dish and Chamfer

Pellet dish and chamfer volumes are assumed to be 1% of fuel stack volume and calculated as follows.

$$\text{Pellet Dish \& Chamfer Volume} = 0.01\pi \times (\text{Pellet OD}/2)^2 \times \text{Stack Length}$$
$$= 0.01\pi \times (10.71/2)^2 \times 480.96$$
$$= 433.3 \text{ mm}^3$$

where, average pellet OD = 10.71 mm [1], average stack length = 480.96 mm [1].

b. Radial Gap Volume

Radial gap volume is calculated in accordance with the following equation.

$$\text{Radial gap volume} = \pi \times ((\text{Sheath ID}/2)^2 - (\text{Pellet OD}/2)^2) \times \text{Stack Length}$$
$$= \pi \times ((10.7858/2)^2 - (10.71/2)^2) \times 480.96$$
$$= 615.5 \text{ mm}^3$$

where, average sheath ID = 10.7858 [1].

c. Axial Gap Volume

Axial gap is calculated as follows.

Axial gap volume = $\pi \times (\text{Sheath ID}/2)^2 \times$ Axial Gap

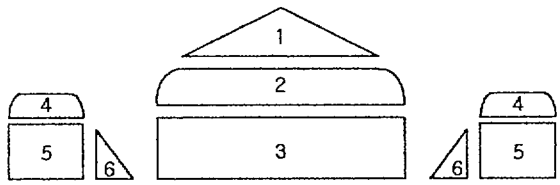
$= \pi \times (10.7858/2)^2 \times 1.92$

$= 175.4\ mm^3$

where, axial gap = 1.92 mm [1].

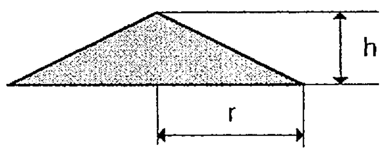
d. End-cap Void Volume

To calculate the volume of the end-cap void, it was sectioned into six parts as follows. Sections #1, #2 and #3 are axisymmetric volumes and #4, #5 and #6 are ring volumes.



Please refer to the fabrication drawing CKF/FA/DW201-2 Rev.3[2] for the ∅11.5 end-cap dimensions used in the following calculation.

<u>**Part #1**</u>



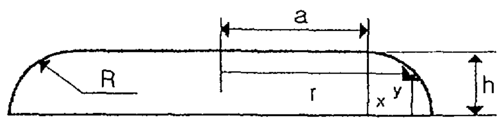
$h = 2.19 - 1.20 = 0.99$ mm

$r = 6.04/2 - 0.5 = 2.52$ mm

$\therefore\ \mathbf{V_1 = 1/3\ \pi\ r^2\ h = \pi/3\ (2.52)^2\ (0.99)}$

$\mathbf{= 6.6\ mm^3}$

Part #2



R = 0.5 mm; h = 0.5 mm, a = 2.52 mm

$x^2 + y^2 = 0.5^2$, $x = (0.5^2 - y^2)^{1/2}$

$r = a + x$

$= 2.52 + (0.5^2 - y^2)^{1/2}$

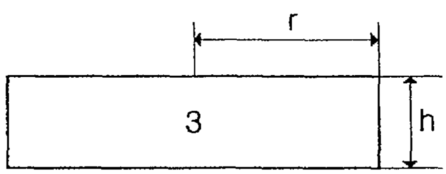
$A_y = \pi r^2$

$= \pi [2.52 + (0.5^2 - y^2)^{1/2}]^2$

$\therefore$ $\mathbf{V_2} = \int_0^{0.5} A_y \, dy$

$= \mathbf{13.3\ mm^3}$

Part #3

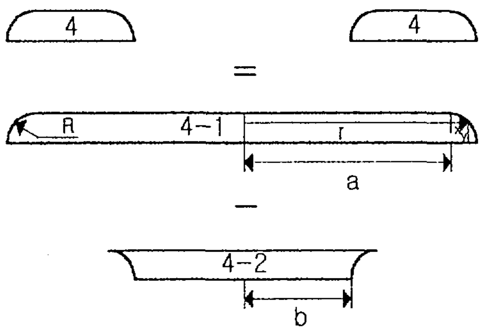


r = 3.02 mm, h = 0.7 mm

$\therefore$ $\mathbf{V_3} = \pi (3.02)^2 (0.7)$

$= \mathbf{20.1\ mm^3}$

Part #4



a = 4.82 mm,   b = 3.997 mm,   R = 0.5 mm

Part #4-1

$r = a + x$
$= 4.82 + (0.5^2 - y^2)^{1/2}$

$A_y = \pi r^2$
$= \pi [4.82 + (0.5^2 - y^2)^{1/2}]^2$

$V_{4\text{-}1} = \int_0^{0.5} A_y dy$
$= 42.7 \text{ mm}^3$

Part #4-2

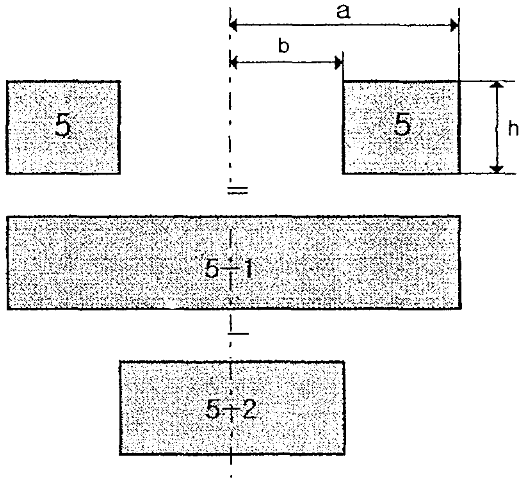
$r = b + x$
$= 3.997 + (0.5^2 - y^2)^{1/2}$

$A_y = \pi r^2$
$= \pi [3.997 + (0.5^2 - y^2)^{1/2}]^2$

$V_{4\text{-}2} = \int_0^{0.5} A_y dy$
$= 30.3 \text{ mm}^3$

$\therefore$ $\mathbf{V_4 = V_{4\text{-}1} - V_{4\text{-}2}}$
$\mathbf{= 12.4 \text{ mm}^3}$

Part #5



a = 5.32 mm,   b = 3.997 mm

Part #5-1

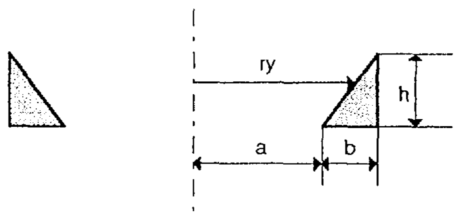
$V_{5\text{-}1} = \pi\, a^2\, h = \pi\, (5.32)^2\, (0.7)$
$= 62.2\ mm^3$

Part #5-2

$V_{5\text{-}2} = \pi\, a^2\, h = \pi\, (3.997)^2\, (0.7)$
$= 35.1\ mm^3$

$\therefore\ \mathbf{V_5 = V_{5\text{-}1} - V_{5\text{-}2}}$
$\mathbf{= 27.1\ mm^3}$

Part #6



a = 3.77 mm, h = 0.7 mm, b = h tan 18° = 0.227 mm

$$r_y = a + (b/h)\, y$$
$$= 3.77 + (0.227/0.7)\, y$$

$$A_y = \pi\, (r_y)^2$$

$$V_{\text{inner volume}} = \int_0^{0.5} A_y\, dy$$
$$= 33.2\ \text{mm}^3$$

$$V_{\text{cylinder}} = \pi\, (3.997)^2\, (0.7)$$
$$= 35.1\ \text{mm}^3$$

$$\therefore\ \mathbf{V_6 = V_{cylinder} - V_{inner\ volume}}$$
$$\mathbf{= 1.9\ mm^3}$$

$$\therefore\ \mathbf{\varnothing 11.5\ End\text{-}cap\ Void\ Volume = V_1 + V_2 + V_3 + V_4 + V_5 + V_6}$$
$$\mathbf{= 81.4\ mm^3}$$

$$\therefore\ \mathbf{\varnothing 11.5\ Fuel\ Element\ Void\ Volume = 1305.6\ mm^3}$$

2. Void Volume of the ∅13.5 Fuel Element

a. Pellet Dish and Chamfer

Pellet dish and chamfer volumes are assumed to be 1% of fuel stack volume and calculated as follows.

$$\text{Pellet Dish \& Chamfer Volume} = 0.01\pi \times (\text{Pellet OD}/2)^2 \times \text{Stack Length}$$
$$= 0.01\pi \times (12.66/2)^2 \times 482.74$$
$$= 607.7 \text{ mm}^3$$

where, average pellet OD = 12.66 mm [1], average stack length = 482.74 mm [1].

b. Radial Gap Volume

Radial gap volume is calculated in accordance with the following equation.

$$\text{Radial gap volume} = \pi \times ((\text{Sheath ID}/2)^2 - (\text{Pellet OD}/2)^2) \times \text{Stack Length}$$
$$= \pi \times ((12.735/2)^2 - (12.66/2)^2) \times 482.74$$
$$= 722.1 \text{ mm}^3$$

where, average sheath ID = 12.735 [1].

c. Axial Gap Volume

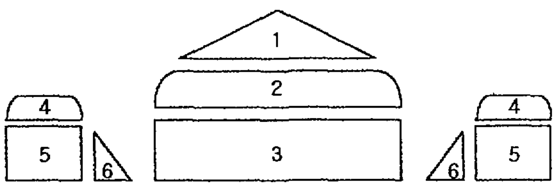
Axial gap is calculated as follows.

$$\text{Axial gap volume} = \pi \times (\text{Sheath ID}/2)^2 \times \text{Axial Gap}$$
$$= \pi \times (12.735/2)^2 \times 1.81$$
$$= 230.6 \text{ mm}^3$$

where, axial gap = 1.81 mm [1].

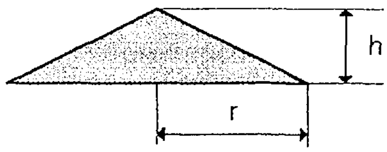
d. End-cap Void Volume

To calculate the volume of the end-cap void, it was sectioned into six parts as follows. Sections #1, #2 and #3 are axisymmetric volumes and #4, #5 and #6 are ring volumes.



Please refer to the fabrication drawing CKF/FA/DW202-3 Rev.0[3] for the ∅13.5 end-cap dimensions used in the following calculation.

Part #1



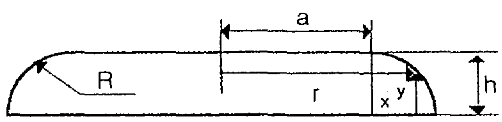
$h = 0.744$ mm

$r = 3.5$ mm

$\therefore$ $\mathbf{V_1} = 1/3\ \pi\ r^2\ h = \pi/3\ (3.5)^2\ (0.744)$

$= \mathbf{9.5\ mm^3}$

Part #2



$R = 0.5$ mm, $h = 0.5$ mm, $a = 3.5$ mm

$x^2 + y^2 = 0.5^2$, $x = (0.5^2 - y^2)^{1/2}$

$r = a + x$

$= 3.5 + (0.5^2 - y^2)^{1/2}$

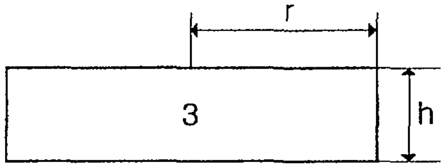
$A_y = \pi\ r^2$

$= \pi\ [3.5 + (0.5^2 - y^2)^{1/2}]^2$

$\therefore$ $\mathbf{V_2} = \int_0^{0.5} A_y\, dy$

$= \mathbf{23.8\ mm^3}$

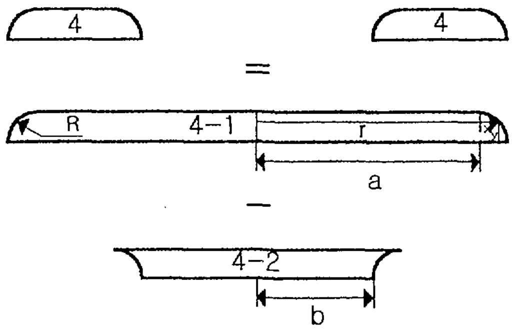
Part #3



r = 4 mm,   h = 0.656 mm

$$\therefore \mathbf{V_3} = \pi\,(4)^2\,(0.656)$$
$$= \mathbf{33.0\ mm^3}$$

Part #4



a = 5.79 mm, b = 5.095 mm, R = 0.5 mm

Part #4-1

$r = a + x$
$= 5.79 + (0.5^2 - y^2)^{1/2}$

$A_y = \pi r^2$
$= \pi [5.79 + (0.5^2 - y^2)^{1/2}]^2$

$V_{4\text{-}1} = \int_0^{0.5} A_y dy$
$= 60.1\ mm^3$

Part #4-2

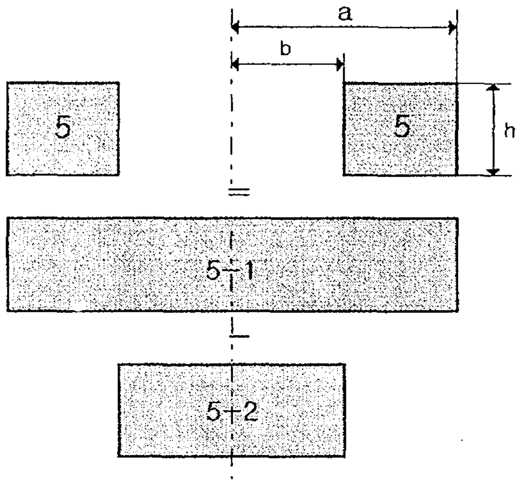
$r = b + x$
$= 5.095 + (0.5^2 - y^2)^{1/2}$

$A_y = \pi r^2$
$= \pi [5.095 + (0.5^2 - y^2)^{1/2}]^2$

$V_{4\text{-}2} = \int_0^{0.5} A_y dy$
$= 47.3\ mm^3$

$\therefore$ $\mathbf{V_4 = V_{4\text{-}1} - V_{4\text{-}2}}$
$\mathbf{= 12.8\ mm^3}$

Part #5



a = 6.29 mm, b = 5.095 mm, h = 0.63 mm

Part #5-1

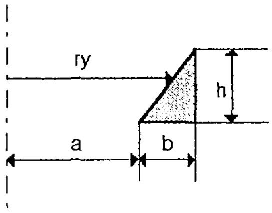
$$V_{5\text{-}1} = \pi a^2 h = \pi (6.29)^2 (0.63)$$
$$= 78.3 \text{ mm}^3$$

Part #5-2

$$V_{5\text{-}2} = \pi a^2 h = \pi (5.095)^2 (0.63)$$
$$= 51.4 \text{ mm}^3$$

$$\therefore \mathbf{V_5 = V_{5\text{-}1} - V_{5\text{-}2}}$$
$$\mathbf{= 26.9 \text{ mm}^3}$$

Part #6



$a = 4.89$ mm, $h = 0.63$ mm, $b = h \tan 18° = 0.205$ mm

$$r_y = a + (b/h)\,y$$
$$= 4.89 + (0.205/0.63)\,y$$

$$A_y = \pi\,(r_y)^2$$

$$V_{\text{inner volume}} = \int_0^{0.5} A_y\,dy$$
$$= 49.3\ \text{mm}^3$$

$$V_{\text{cylinder}} = \pi\,(4.89 + 0.205)^2\,(0.63)$$
$$= 51.4\ \text{mm}^3$$

$\therefore$ **$V_6 = V_{\text{cylinder}} - V_{\text{inner volume}}$**
$= 2.1\ \text{mm}^3$

$\therefore$ **Ø13.5 End-cap Void Volume = $V_1 + V_2 + V_3 + V_4 + V_5 + V_6$**
$= 108.1\ \text{mm}^3$

$\therefore$ Ø13.5 Fuel Element Void Volume = 1668.5 mm^3

Reference

[1] Moon-Sung Cho, Fabrication Report – Fabrication of CANFLEX-RU designed Bundle for Power Ramp Irradiation Test in NRU", KAERI Technical Report KF-FR-99-01 Rev. 1, June 7, 2000.

[2] Fuel bundle fabrication drawing, "End Cap," CKF/FA/DW-201-2, Rev.3, KAERI, February 15, 1994.

[3] Fuel bundle fabrication drawing, "End Cap," CKF/FA/DW-202-3, Rev.0, KAERI, July 11, 1996.

Moon-Sung Cho

Attachment 3. Certificate of Analysis

유니온가스
UNION CARBIDE

유니온가스
본 사: 서울 중구 ...
TEL: (02 ...
제1공장: 경남 창원시 ...
TEL: (05 ...
제2공장: 경기도 화성 ...
TEL: (03 ...

가스분석성적서
(Certificate of Analysis)

Date: 1989. 12. 19.

* *

주 문 처: 한국에너지연구소
Customer

분석번호: GSL - - - GH - 1959
Anal. No.

SAMPLE CYLINDER NUMBER HK 00826

HE CONTAINER NUMBER 1930

용기번호 Cyl. No.		분석성분 Component	분석결과 Certified Composition	비고 Remark
HK 00826	HK 00341	HE(HP)	99.996% 이상	
00920	00295			
00037	01667	H2	9 PPM	
00513	00370			
00721	00061	N2	27 PPM	
00330	00815			
00810	01175	HALOGENS	FREE	
00314	00175			
00783		OTHERS(O2,H2O)	8 PPM	
00101				
00326				
00072				
00616				
00635				
00710				
00257				
00298				
00238				
00160				
00177				
00933				
00527				

분석일자: 1989. 12. 16
Date of Anal.

용기규격: T
Type of Cyl.

충전압력: 135 (Kg/cm², 35°C)
Filling Pressure

12/20

승인자
Approved

유니온가스 UNION CARBIDE

유 니 온 가 [illegible] 사
본 사 : 서울 · 중구 [illegible] 50 [illegible]
TEL : (02 [illegible]
제 1 공장 : 경남 창원시 [illegible] 2 - [illegible]
TEL : (05 [illegible]
제 2 공장 : 경기도 화성 [illegible] 3
TEL : (03 [illegible] 2600 [illegible]

가스분석성적서

(Certificate of Analysis)

Date : 1989 .9 . 25.

* *

주 문 처 : 한국에너지 연구소
Customer

분석번호 : GSL - GH - 1419
Anal. No.

HE CONTAINER NUMBER : 1997

용 기 번 호 Cyl. No.		분 석 성 분 Component	분 석 결 과 Certified Composition	비 고 Remark
HK 00860	00547	HE(HP)	99.996% 이상 ✓	
01038	01577			
01086	00497	H2	10PPM 이하 ✓	
00195	00196	N2	30PPM 이하 ✓	
00889	00363			
00533	00708	HALOGENS	FREE ✓	
00190	00495			
00877	00393	OTHERS(O2, H2O)	10PPM 이하 ✓	
00194	00111			
00317	00525			
00075	00083			
	..107			
00320	00206			
01212	00756			
00121	00213			

확인필
품질관리
89. 9. 26.

분 석 일 자 : 1989.9.21.
Date of Anal.

용 기 규 격 :
Type of Cyl.

충 전 압 력 : 135 (Kg/cm², 35°C)
Filling Pressure

승 인 자
Approved

유니온가스
UNION CARBIDE

유니온가스
본 사: 서울·중구 ...
TEL: (02 ...
제1공장: 경남 창원시 ...
TEL: (05 ...
제2공장: 경기도 화성 ...
TEL: (03...

가스분석성적서

(Certificate of Analysis)

Date: 1989. 7. 18.

* *

주 문 처: 한국 에너지 연구소
Customer

분석번호: GSL - GH - 1109
Anal. No.

° HE CONTAINER NUMBER 1997.

용 기 번 호 Cyl. No.	분 석 성 분 Component	분 석 결 과 Certified Composition	비 고 Remark
HK 00673 01572	HE (HP)	MORE THAN 99.996%	
00202 00080	H2	10 PPM 이하	
01176 01301	N2	30 PPM 이하	
00265 00279	HALOGENS	FREE	
00162 00013	OTHERS	10 PPM 이하	
00357 00856			
00161 00485			
00189 00097			
00071 01048			
00292 00766			
00297 00868			
00337 00493			
00171 00613			
00471 00555			
00050 01410			

확인필
품질관리실
89. 7. 19

분 석 일 자: 1989. 7. 14.
Date of Anal.

용 기 규 격: T
Type of Cyl.

충 전 압 력: 135 (Kg/cm², 35°C)
Filling Pressure

승 인 자
Approved

유니온가스
UNION CARBIDE

본 사 : 서울 ... TEL : ...
제1공장 : 경남 ... TEL : ...
제2공장 : 경기도 ... TEL : ...

가 스 분 석 성 적 서
(Certificate of Analysis)

Date : 1989 . 5 . 3 .

* *

주 문 처 : 한국에너지 연구소
Customer

분석번호 : GSL - GH - 0539
Anal. No.

용기번호 Cyl. No.		분석성분 Component	분석결과 Certified Composition	비고 Remark
00531	HK 00957			
00804	00474	HE(HP)	99.996% 이상	
01610	00884	O2	5 PPM 이하	
00316	00402	H2O	5 PPM 이하	
00181	00299	H2	10 PPM 이하	
00256	00776	N2	30 PPM 이하	
00406	01078	HAlOGENS	FREE	
01355	00518			
00973				
00200				
00277				
00321				
00462				
00630				
01653				
00078				
00783				
01196				
01147				
00313				
00443				
9				

확인필
품질관리실
9.5.1.

분석일자 : 1989. 4 . 30
Date of filling

용기규격 : T
Cyl. Type

충전압력 :
Filling Pressure 135 (Kg/Cm^2)

승 인 자
Approved

Attachment 4. Inspection Report

검 사 성 적 서
INSPECTION REPORT

일련 번호 IPH - 96 - 012

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 :
☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.05 PPM	0.033(mg)	N/A	Lot No. : 96 L 048 Batch No : UP610P
		2	.06			
		3	.06			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스					

비 고 :
* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게
** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
2. 피복관내 수소함유량 : 0.5 mg 이하
3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification
검 사 자 : Inspected by 진 정식 (signature)	검사일자 : Date 96. 11. 28	(stamp) 품질관리실
판 정 자 : Verified by 박 정주 (signature)	판정일자 : Date '96. 11. 28	

검 사 성 적 서
INSPECTION REPORT

일련 번호 IPH - P6 - 011

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 :
☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.03 (PPM)	0.024 (mg)	N/A	Lot No. : P6L047 Batch No. UP60P8
		2	.04			
		3	.05			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스					

비 고 :
* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게

** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
2. 피복관내 수소함유량 : 0.5 mg 이하
3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification
검 사 자 : Inspected by 진 정식	검사일자 : Date 1996. 11. 28	HWR 합 격 품질관리실
판 정 자 : Verified by 박 정주	판정일자 : Date '96. 11. 28	

검 사 성 적 서

INSPECTION REPORT

일련 번호 IPH-P6-011

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 :
☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.04 (PPM)	0.090 mg	N/A	Lot No : P5LIP3 Batch No : UP6084
		2	0.35			
		3	0.07			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스					

비 고 :

* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게

** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
2. 피복관내 수소함유량 : 0.5 mg 이하
3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification HWR 합격 품질관리실
검 사 자 : Inspected by 진 정식	검사일자 : Date 96.10.17	
판 정 자 : Verified by 박 철주	판정일자 : Date 96.10.17	

검 사 성 적 서

INSPECTION REPORT　　　일련 번호 IPH - P6 - 00

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :

☒ 피복관 Batch 번호 :

☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.04 (PPM)	0.035 mg	N/A	Lot No : P5L1P7 Batch NO : UP6072
		2	0.06			
		3	0.08			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스					

비 고 :

* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게

** 연료봉내 총 수소함유량 = A+B+C

검사기준　1. 연료봉내 총수소함유량 : 0.6 mg 이하

　　　　　2. 피복관내 수소함유량 : 0.5 mg 이하

　　　　　3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification (stamp: HWR 합 품질관리실)
검 사 자 : Inspected by 진 정식 (signature)	검사일자 : Date 96.10.17	
판 정 자 : Verified by 박 철주 (signature)	판정일자 : Date 96.10.17	

검 사 성 적 서

INSPECTION REPORT　　　일련 번호 IPH - P6 - 00

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 :
☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.06 (ppm)	0.041 mg	N/A	Lot No : P5L066 Batch No. : UP6002
		2	0.07			
		3	0.08			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스					

비 고 :

* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게

** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
2. 피복관내 수소함유량 : 0.5 mg 이하
3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification HWR 합격 품질관리실
검 사 자 : Inspected by 진 정숙 (signature)	검사일자 : Date 96. 10. 17	
판 정 자 : Verified by 박 정국 (signature)	판정일자 : Date '96. 10. 17	

검 사 성 적 서
INSPECTION REPORT

일련 번호 1PH-P6-001

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 :
☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.08 (PPM)	0.031 mg	N/A	Lot No. P5L088 Batch No : ~~U P5125~~ U P5125
		2	0.02			
		3	0.05			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스					

비 고 :
* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게
** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
2. 피복관내 수소함유량 : 0.5 mg 이하
3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification HWR 합 격 품질관리실
검 사 자 : Inspected by 진 정욱	검사일자 : Date 96.10.17	
판 정 자 : Verified by 박 철희	판정일자 : Date 96.10.17	

QA 7110 Rev.1 A4 (210x297)

검 사 성 적 서

INSPECTION REPORT 　　　　일련 번호 1PH96-006

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 :
☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.05 ppm	0.022 mg	N/A	Lot NO. 95L064 (U : 96054)
		2	0.03 "			
		3	0.06 "			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스		N/A			

비 고 :

* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게

** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
　　　　2. 피복관내 수소함유량 : 0.5 mg 이하
　　　　3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification HWR 합격 품질관리실
검 사 자 : Inspected by 김국회 (signature)	검사일자 : Date '96.8.21	
판 정 자 : Verified by 박철주 (signature)	판정일자 : Date '96.8.21	

검 사 성 적 서
INSPECTION REPORT

일련 번호 1PH96-005

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 :
☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.06 ppm	0.086 mg	N/A	Lot NO. 95L192 (U:96060)
		2	0.08 "			
		3	0.15 "			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스		N/A			

비 고 :
* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게

** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
2. 피복관내 수소함유량 : 0.5 mg 이하
3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification HWR 합 격 품질관리실
검 사 자 : Inspected by 김국희	검사일자 : Date 96. 8. 21	
판 정 자 : Verified by 박철구	판정일자 : Date '96. 8. 21	

QA 7110 Rev.1 A4 (210x297)

검 사 성 적 서

INSPECTION REPORT

일련 번호 고7月 96004

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 :
☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.104 ppm	0.027 mg	N/A	Lot No: 95L198 (U:96048)
		2	0.04 "			
		3	0.06 "			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스		N/A			

비 고 :

* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게

** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
2. 피복관내 수소함유량 : 0.5 mg 이하
3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification WR 합 격 품질관리실
검 사 자 : Inspected by 김국희 (signature)	검사일자 : Date '96. 7. 26	
판 정 자 : Verified by 박 철주 (signature)	판정일자 : Date '96. 7. 27	

검 사 성 적 서
INSPECTION REPORT

일련 번호 고개 96-003

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 :
☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.04 ppm	0.029 mg		Lot No : 9EL196 (U:96040)
		2	0.07 ″			
		3	0.04 ″			
B	흑연도포 제거피복관	1		N/A	N/A	
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스		N/A			

비 고 :
* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게
** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
2. 피복관내 수소함유량 : 0.5 mg 이하
3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification HWR 합 격 품질관리실
검 사 자 : Inspected by 강국희 (signature)	검사일자 : Date '96. 7. 26	
판 정 자 : Verified by 박철주 (signature)	판정일자 : Date '96. 7. 27	

QA 7110 Rev.1 A4 (210x297)

검 사 성 적 서
INSPECTION REPORT

일련 번호 ℤPH96-002

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 : N/A
☒ 연료봉 Type : W705

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.05 ppm	0.029mg	N/A	Lot NO: 95L194 (U96028)
		2	0.04 "			
		3	0.06 "			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6				
C	장입 가스		N/A			

비 고 :
* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게
** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
2. 피복관내 수소함유량 : 0.5 mg 이하
3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification KWR 합 격 품질관리실
검 사 자 : Inspected by 진 정숙 (signature)	검사일자 : Date 96. 6. 21	
판 정 자 : Verified by 박 철주 (signature)	판정일자 : Date 96. 6. 21	

검 사 성 적 서

INSPECTION REPORT　　　　일련 번호 JPH96-001

품질관리실 QC DEPT	검사명 : 연료봉(피복관, 소결체)내의 수소 함유량 분석 Title	페이지 Page

☒ 연료봉 Kit 번호 :
☒ 피복관 Batch 번호 :　N/A
☒ 연료봉 Type :

시편 \ 항목			수소함유량	평균수소함유량	연료봉내 총수소 함유량	비 고
A	소결체	1	0.02 ppm	0.026mg	N/A	Lot NO: 95L195 (U96026)
		2	0.09 "			
		3	0.02 "			
B	흑연도포 제거피복관	1		N/A		
		2				
	흑연도포 피복관	3				
		4				
		5				
		6		*		
C	장입 가스		N/A			

비 고 :
* 흑연 도포층내의 평균 수소함유량 = (흑연도포 피복관의 평균 수소함유량 - 흑연도포제거 피복관의 평균 수소함유량) x 피복관 무게
** 연료봉내 총 수소함유량 = A+B+C

검사기준 1. 연료봉내 총수소함유량 : 0.6 mg 이하
2. 피복관내 수소함유량 : 0.5 mg 이하
3. 소결체내 수소함유량 : 0.5 ppm 이하

적용시방서 및 도면번호 : Spec.& Dwg. No. QCI-163, 722, 751	검사방법 : Deg. of Insp	판 정 : Verification HWR 합 격 품질관리실
검 사 자 : Inspected by 진 정석 (signature)	검사일자 : Date 96. 6. 21	
판 정 자 : Verified by 박 철구 (signature)	판정일자 : Date 96. 6. 21	

KAERI
HWR FUEL DIV.

이산화우라늄 소결체 특성검사

일련번호 : CISP - 95 - 004

뱃취번호 : CN 9504	뱃취크기 : 4,910 EA	소결체종류 : S	페이지 1

밀도 검사 10.47~10.73 g/cc	직경 (mm) 상	직경 (mm) 중	시료 무게 (g)	크래들+시료 물속무게 (g)	크래들 물속무게 (g)	젖은시료 무게 (g)	물의 온도 (°C)	소결체 밀도 (g/cc)
	10.88	10.80	12.7717	11.5890	0	N/A	0.9973	10.77
	.88	.78	.9928	.6084	0	"	"	.77
판정:	.89	.78	.7987	.6122	0	"	"	.76
	.91	.80	.8675	.6759	0	"	"	.77

O/U 비 검사 1.995~2.015	용기 무게 (g)	용기+시료 무게 /시료무게(g)		1차 산화후 용기+시료/시료 무게(g), WI1		2차 산화후 용기+시료/시료 무게(g), WI2		X (WI1-WI2)	O/U 비
판정:									

표면결함 검사	시료갯수	결함	끝단칩	원주칩	핏트	이물질	크랙	캡핑	기타	합계
판정:	200EA	내용	1	-	-	-	-	-	-	1

치수 및 표면조도

직경   시료갯수 : 50 EA

	正正正正	20
10.710	正正正正正下	28
	T	2

C: 0.004   x:10.708
x:10.7134   S:0.0023
U: 10.73   L: 10.70
Qu: 7.27   Ql: 5.83
Pu: 0   Pl: 0
P: 0   M: 1.91

0.24

길이 (mm)	직각도 (mm)	홈깊이 (mm)	어깨폭 (mm)	표면조도 (Ra, μm)
12.99	0.02	0.20	0.24	0.18
.94	.01	.21	.25	.17
13.07	.02	.20	.23	.17
.02	.01	.19	.24	.18
.04	.01	.20	.24	.18

판정:

조직 검사	분말과립 유무	결정립 크기 (μm)	평균 결정립 크기 (μm)
판정:	무	9.9 9.8 10.0 9.9	9.90

Fe 분석	<200 ppm	ppm
판정:	해당 없음	

장전길이	불량갯수/시료갯수 :
판정:	해당 없음

측정기기	기기번호	비고
Electronic Balance	39090013	
Digimatic M/M	413996	
Disc M/M	4426515	
Dial Indicator	004221	
Profile Projector	BP-30	
Surf. Rough. Tester	02799	
Digimatic Caliper	7001701	

검사자 : 권정식 (서명) 95.9.20   판정자 :

이산화우라늄 소결체 특성검사

KAERI
HWR FUEL DIV.

일련번호 : CISP - P5 - 006

뱃취번호 : CFT P506	뱃취크기 : 14.708 EA	소결체종류 : L	페이지 1

밀도 검사	직경 (mm) 상	직경 (mm) 중	시료 무게 (g)	크래들+시료 물속무게 (g)	크래들 물속무게 (g)	젖은시료 무게 (g)	물의 온도 (°C)	소결체 밀도 (g/cc)
10.47~ 10.73 g/cc	10.88	10.84	13.6418	12.3835	0	N/A	0.8873	10.77
	.86	.84	.5040	.2527	0			.76
판정:	.86	.82	.6222	.3584	0			.76
	.86	.81	.6718	.3588	0			.76

O/U 비 검사	용기 무게 (g)	용기+시료 무게/시료무게(g)		1차 산화후 용기+시료/시료 무게(g), WI1		2차 산화후 용기+시료/시료 무게(g), WI2		X (WI1-WI2)	O/U 비
1.995~ 2.015	30.2516	43.7752	13.4236	44.3062	13.8536	44.3053	13.8537	0.0001	2.0001
	.0514	.1156	.0642	43.6316	.5802	43.6316	.5802	.	.0000
판정:	.1468	.5308	.3840	44.0580	.8512	44.0583	.8125	0.0003	.0002
	33.4460	36.7522	.3062	37.2774	.8314	37.2776	.8316	0.0002	.0005

표면결함 검사	시료갯수	결함	끝단칩	원주칩	핏트	이물질	크랙	챕핑	기타	합계
판정:	315 EA	내용	1	-	-	-	-	-	-	0

치수 및 표면조도

직경 시료갯수 : 40 EA

	—	
	正正正	15
10.710	正正正正	18
	正一	6

C: 0.004 x: 10.708
x: 10.7128 S: 0.0028
U: 10.73 L: 10.70
Qu: 6.11 Ql: 6.61
Pu: 0 Pl: 0
P: 0 M: 1.88

0.242

길이 (mm)	직각도 (mm)	홈 깊이 (mm)	어깨폭 (mm)	표면조도 (Ra, μm)
14.74	0.01	0.30	0.23	0.18
.72	.02	.30	.25	.16
.76	.01	.21	.24	.16
.74	.02	.20	.25	.16
.72	.02	.20	.24	.18

판정:

조직 검사	분말과립 유무	결정립 크기 (μm)	평균 결정립 크기 (μm)
판정:	해당 없음		

Fe 분석	<200 ppm	ppm
판정:	해당 없음	
장전길이	불량갯수/시료갯수 : 0/80	
판정:		

측정기기	기기번호	비고
Electronic Balance	39090013	
Digimatic M/M	413996	
Disc M/M	4426515	
Dial Indicator	004221	
Profile Projector	BP-30	
Surf. Ruugh. Tester	02799	
Digimatic Caliper	7001701	

검사자 : 진정식 95.8.20

판정자 :

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<tr><td colspan="2">KAERI/TR-1663/2000</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">제목 / 부제</td><td colspan="6">Fabrication of a CANFLEX-RU Designed Bundle for Power Ramp Irradiation Test in NRU</td></tr>
<tr><td colspan="2">연구책임자 및 부서명</td><td colspan="6">조문성 (핵연료설계기술개발팀)</td></tr>
<tr><td colspan="2">연구자 및 부서명</td><td colspan="6"></td></tr>
<tr><td>출판지</td><td>대전</td><td>발행기관</td><td colspan="2">한국원자력연구소</td><td>발행년</td><td colspan="2">2000.11</td></tr>
<tr><td>페이지</td><td>p.59</td><td>도표</td><td colspan="2">있음(0), 없음( )</td><td>크기</td><td colspan="2">29× 21 Cm</td></tr>
<tr><td>참고사항</td><td colspan="7"></td></tr>
<tr><td>비밀여부</td><td colspan="3">공개(V), 대외비( ), __ 급비밀</td><td>보고서종류</td><td colspan="3">기술보고서</td></tr>
<tr><td colspan="2">연구위탁기관</td><td colspan="2"></td><td>계약 번호</td><td colspan="3"></td></tr>
<tr><td colspan="8">초록 (15-20줄내외)

BDL-443 CANFLEX-RU AKW 다발은 캐나다 NRU 원자로에서의 출력급증시험에 사용될 목적으로 한국원자력연구소에서 제작되었다. 동 핵연료 다발에는 IDR 및 ADU 타입 핵연료 소결체가 한 칸씩 격봉 장입되었으며 외환 및 중환봉에는 1.65 wt% ^{235}U를, 소결체, 내환봉에는 2.00 wt% ^{235}U 소결체를 장입하였다. 행거 바의 삽입을 위해 동 다발의 중심봉을 제거하였다.
IDR 소결체는 BNFL이 제공한 IDR 타입 UO_2 분말을 사용하여 한국원자력연구소에서 제작하였으며 ADU 소결체는 AECL이 제작 공급하였다. 다발 키트 (지르칼로이-4 봉단 접합판, 봉단 마개, 피복관) 는 1996년 CANFLEX 핵연료 다발 제작을 위해 한국원자력연구소에서 제작한 것을 사용하였다. 동 다발은 관련 품질보증 규정과 도면 및 시방서 등에 따라 성공적으로 제작되었다. 본 보고서는 한국원자력연구소에서 수행한 제작업무에 대해서만 기술하였으며 ADU 소결체에 대한 제작업무는 AECL이 발행하는 별도의 보고서에 기술될 것이다.</td></tr>
<tr><td colspan="2">키워드
(10단어내외)</td><td colspan="6">CANFLEX, RU, Fuel, Fabrication, IDR, ADU, NRU, Power Ramp, Irradiation, AKW</td></tr>
</table>

BIBLIOGRAPHIC INFORMATION SHEET

Performing Org. Report No.	Sponsoring Org. Report No.	Stamdard Report No.	INIS Subject Code
KAERI/TR-1663/2000			

Title/Subtitle	Fabrication of a CANFLEX-RU Designed Bundle for Power Ramp Irradiation Test in NRU
Author and Department	Cho, Moon-Sung (Nuclear Fuel Development Team)
Researcher and Department	

Publication Place	Taejon	Publisher	KAERI	Publication Date	2000.11
Page	p. 59	Ill. & Tab.	Yes(O), No ( )	Size	29 × 21 Cm
Note					
Classified	Open(O), Restricted( ), ___ Class Document		Report Type	Technical Report	
Sponsoring Org.			Contract No.		

Abstract (15-20 Lines)

The BDL-443 CANFLEX-RU bundle AKW was fabricated at Korea Atomic Energy Research Institute (KAERI) for power ramp irradiation testing in NRU reactor. The bundle was fabricated with IDR and ADU fuel pellets in adjacent elements and contains fuel pellets enriched to 1.65 wt% ^{235}U in the outer and intermediate rings and also contains pellets enriched to 2.00 wt% ^{235}U in the inner ring. This bundle does not have a center element to allow for insertion on a hanger bar.

KAERI produced the IDR pellets with the IDR-source UO_2 powder supplied by BNFL. ADU pellets were fabricated and supplied by AECL. Bundle kits (Zircaloy-4 end plates, end plugs, and sheaths with brazed appendages) manufactured at KAERI earlier in 1996 were used for the fabrication of the bundle. The CANFLEX bundle was fabricated successfully at KAERI according to the QA provisions specified in references and as per relevant KAERI drawings and technical specification. This report covers the fabrication activities performed at KAERI. Fabrication processes performed at AECL will be documented in a separate report.

Subject Keywords (About 10 words)	CANFLEX, RU, Fuel, Fabrication, IDR, ADU, NRU, Power Ramp, Irradiation, AKW