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History and Current Status of LEU-7Mo Atomized Powder Fabricated in KAERI

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1. Introduction

Under the nuclear non-proliferation policy, International Atomic Energy Agency (IAEA) and advanced counties emphasize the importance of minimizing the use of highly enriched uranium(HEU, more than 90% enrichment in ^{235}U) and encourage to replace HEU with low-enriched uranium(LEU, less than 20% enrichment in ^{235}U) for high power research reactors(HPRR).

To compensate fissile material for conversion from HEU to LEU, it has been required to use high-density LEU fuel. Through comprehensive study on U alloy candidates, U-7wt.%Mo(U-7Mo) showed stable swelling behavior in numerous in-pile tests and has been chosen as the most prominent candidate [1-3].

For LEU-7Mo powder fabrication, KAERI has been developing atomization technology. The atomization method is a key technology for achieving the high-density LEU fuel because atomized powder is able to have various U-alloy compositions and a high uranium content. Fig. 1 shows the atomization technology that can fabricate spherical powder; its process is much simpler than that of conventional comminuted one. The atomized powder has high purity with fewer defects, excellent irradiation performance, and high production yield rate. After an atomization, sieving process followed to obtain LEU-7Mo powder with diameter under 125 or 150 ㎛.

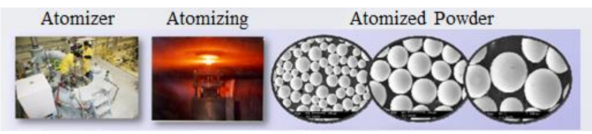

Fig. 1. KAERI Centrifugal Atomization Technology [4]

2. LEU-7Mo Powder Fabricated in 2013 for 2012 NSS Agreement

In 2013, KAERI successfully fabricated LEU-7Mo powder related to the 2012 Seoul Nuclear Security Summit(NSS) agreement between Korea, the US, France and Belgium. The LEU-7Mo powder will be used for making high-density LEU fuel assemblies for HPRR such as RHF-ILL, France and BR-2, Belgium.

LEU-7Mo power fabrication result is presented in Table I and its chemical analysis is presented in Table II. KAERI fabricated 112.84 kg of LEU-7Mo powder. An average production yield rate is 96.54%. M011 and M012 batches exceeded the specification of carbon impurities. Except the 2 batches, remaining 23 batches met the specification of maximum metallic impurities.

Table I: LEU-7Mo powder fabrication result

Batch	Total Loading (g)	Fabricated Powder (g)	Yield Rate (%)
M001	4,252.75	4,094.93	96.29
M002	4,249.81	4,101.57	96.51
M003	4,438.30	4,326.43	97.48
M004	4,293.01	4,162.66	96.96
M005	4,203.00	4,077.98	97.03
M006	4,290.01	4,165.84	97.11
M007	4,768.20	4,640.67	97.33
M008	4,694.16	4,568.26	97.32
M009	4,859.89	4,717.23	97.06
M010	4,899.25	4,779.51	97.56
M011	4,823.66	4,576.03	94.87
M012	4,615.42	4,421.97	95.81
M013	4,636.42	4,492.86	96.90
M014	4,640.63	4,510.84	97.20
M015	4,724.73	4,593.24	97.22
M016	4,678.49	4,121.37	88.09
M017	4,959.96	4,802.58	96.83
M018	4,984.13	4,853.01	97.37
M019	4,726.81	4,591.98	97.15
M020	4,725.88	4,604.45	97.43
M021	4,993.55	4,835.05	96.83
M022	4,889.25	4,726.74	96.68
M023	4,851.55	4,631.74	95.47
M024	4,836.22	4,716.22	97.52
M025	4,856.32	4,729.25	97.38
Sum(Avr.)	116,891.40	112,842.41	96.54

Table II: Chemical Analysis of LEU-7Mo powder

Unit : μg/g *wt%

Batch	C	H	O	N	Al	Fe	Ni
M001	730	3	210	220	9.8	36.7	23.8
M002	590	3	400	240	7.5	25.3	22.5
M003	480	4	490	300	12.1	56.4	24.5
M004	650	3	200	90	11.6	53.5	58.6
M005	670	2	170	20	10.1	59.6	58.9
M006	800	2	380	110	13.7	47.5	60.2
M007	250	6	230	120	12.8	57.5	31.7
M008	270	4	290	140	11.8	55.5	31.6
M009	340	5	300	220	12.4	57.1	29.5
M010	280	6	290	120	12.7	56.8	29.2
M011	1040	6	240	40	11.0	39.5	26.5

M012	700	4	220	230	11.2	41.2	27.7
M013	520	3	320	390	10.3	37.5	27.4
M014	550	3	240	150	10.2	36.1	27.3
M015	510	3	330	140	10.7	34.2	28.0
M016	1550	4	420	150	9.7	32.1	26.7
M017	580	2	180	180	10.0	32.2	26.1
M018	500	2	200	180	10.3	33.1	27.0
M019	420	2	250	270	15.4	37.5	19.6
M020	480	2	240	120	15.0	36.1	20.4
M021	250	3	190	140	13.0	114.5	24.1
M022	490	3	170	20	10.7	44.1	27.1
M023	430	2	340	180	10.4	42.5	27.4
M024	360	2	330	30	10.2	45.0	26.8
M025	390	3	220	20	11.4	14.6	27.7

Table II: Chemical Analysis of LEU-7Mo powder (continue)

Unit : µg/g *wt%

Batch	Cu	B	Cd	Co	Li	Zn	Mo*
M001	15.2	<1	<1	<1	<5	1.3	7.0
M002	12.1	<1	<1	<1	<5	1.3	7.0
M003	18.3	<1	<1	<1	<5	3.6	7.0
M004	29.0	<1	<1	<1	<5	2.1	7.0
M005	29.0	<1	<1	<1	<5	1.4	7.0
M006	28.0	<1	<1	<1	<5	3.4	7.0
M007	19.7	<1	<1	<1	<5	3.3	7.0
M008	15.3	<1	<1	<1	<5	1.7	7.0
M009	15.8	<1	<1	<1	<5	2.1	7.0
M010	16.3	<1	<1	<1	<5	1.9	7.0
M011	15.1	<1	<1	<1	<5	2.8	7.0
M012	15.2	<1	<1	<1	<5	5.2	7.0
M013	15.3	<1	<1	<1	<5	<1	7.0
M014	15.1	<1	<1	<1	<5	2.5	7.0
M015	16.1	<1	<1	<1	<5	2.5	7.0
M016	15.1	<1	<1	<1	<5	<1	7.0
M017	15.3	<1	<1	<1	<5	3.5	7.0
M018	15.8	<1	<1	<1	<5	1.2	7.0
M019	10.4	<1	<1	<1	<5	1.3	7.0
M020	14.3	<1	<1	<1	<5	1.8	7.0
M021	10.0	<1	<1	3.9	<5	1.1	7.0
M022	10.6	<1	<1	<1	<5	<1	7.0
M023	28.8	<1	<1	<1	<5	1.6	7.0
M024	11.2	<1	<1	<1	<5	<1	7.0
M025	14.6	<1	<1	<1	<5	1.5	7.0

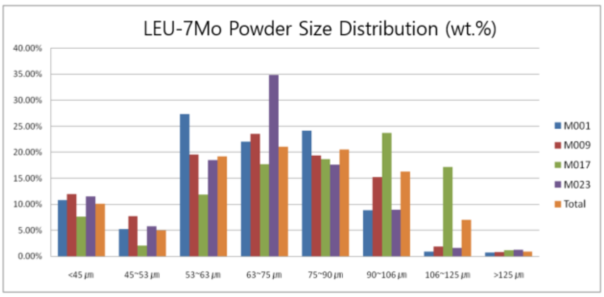

Fig. 2. LEU-7Mo powder size distribution

Powder size distribution analysis is presented in Fig. 2. LEU-7Mo powder with diameter under 125 ㎛ accounts for 99.22 wt.% and the powder with diameter between 63~75 ㎛ is the highest proportion with 21.03 wt.%. After a packing process presented in Fig.3, KAERI transported 98 kg of LEU-7Mo powder to Y-12, the US and 2 kg to SCK·CEN, Belgium in 2014. On Sep. 2021, 50 kg out of the 98 kg powder exported to Y-12 in 2014 will be imported back to KEARI. The 50kg powder will be transported to CERCA on Oct. 2021 to fabricate the high-density LEU fuel assemblies for the HPRRs in France and Belgium. 15 kg of LEU-7Mo scrap will be also transported to Y-12 on Oct. 2021.

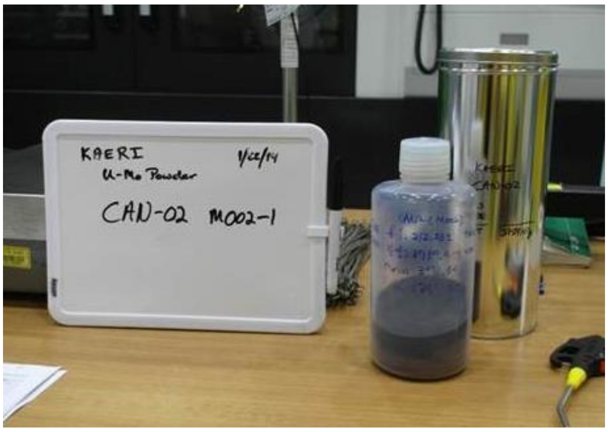

Fig. 3. LEU-7Mo Powder Packing Process

3. LEU-7Mo Powder Fabricated in 2019 for KUCA Project

In 2019, KAERI successfully fabricated LEU-7Mo powder for Kyoto University Critical Assembly (KUCA), Japan presented in Fig. 4. Based on the project agreement at 2016 NSS, KUCA has been officially determined to convert from HEU fuel to LEU fuel and to return all HEU materials to the US. KUCA has three independent cores : two solid-moderated dry cores(A, B) and one light-water moderated wet core(C). KUCA has been used for fundamental research and education on reactor physics since its establishment in 1974[5,6].

Under the agreement, KAERI uses 42 kg of LEU materials imported from the US for LEU-7Mo powder fabrication. The LEU-7Mo powder with diameter under 150 ㎛ is transported to CERCA, France and CERCA manufactures LEU-7Mo/Al dispersion coupon type fuel presented in Fig. 5. The thin fuel "coupons" plates are assembled with polyethylene moderator plates. An aluminum sheath covers coupons and moderator plates and reflectors[5,6].

The coupon type plates will be loaded in KUCA dry cores that are now utilized HEU aluminum alloy fuel. If the project is successfully completed, KUCA will be a first LEU conversion facility using the centrifugally atomized U-Mo powder[7].

Fig. 4. Panoramic view of KUCA, Japan

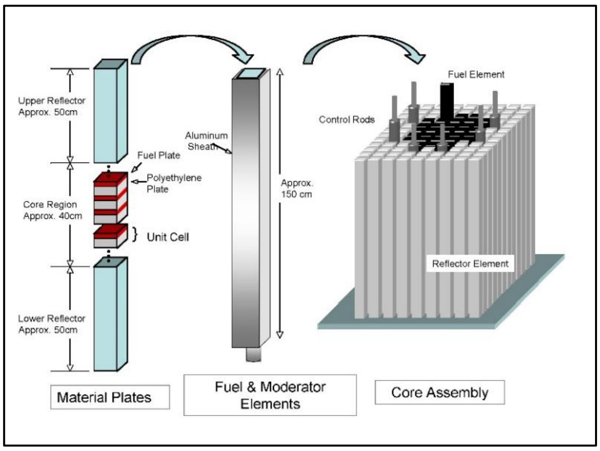

Fig. 5. Schematic View of KUCA Dry Core Fuel Element and Assembly[6]

LEU-7Mo power fabrication result is presented in Table III and its chemical analysis is presented in Table IV. KAERI fabricated 42.80 kg of LEU-7Mo powder. An average production yield rate is 94.77%. All batches met the specification of maximum metallic impurities.

Table III: LEU-7Mo powder fabrication result

Batch	Total Loading (g)	Fabricated Powder (g)	Yield Rate (%)
C1901	3,618.28	3,442.92	95.15
C1902	3,580.65	3,386.49	94.58
C1903	3,567.74	3,381.72	94.79
C1904	3,543.01	3,374.10	95.23
C1905	3,521.51	3,345.05	94.99
C1906	3,518.28	3,328.80	94.61
C1907	3,494.62	3,307.00	94.63
C1908	3,438.71	3,246.34	94.41
C1909	3,429.03	3,279.71	95.65
C1910	3,410.75	3,244.05	95.11
C1911	3,309.68	3,118.54	94.22
C1912	2,998.92	2,800.28	93.38
C1913	3,730.18	3,545.90	95.06
Sum(Avr.)	45,161.36	42,800.90	94.77

Table IV: Chemical Analysis of LEU-7Mo powder

Unit : μg/g *wt%

Batch	C	H	O	N	Al	Fe	Ni
C1901	180	7	130	10	35.7	62.9	52.7
C1902	240	8	400	15	27.1	63.4	42.8
C1903	420	7	330	15	36.8	57.4	45.4
C1904	340	7	330	20	58.2	57.2	48.6
C1905	190	10	580	40	55.6	54.3	42.5
C1906	340	13	830	70	52.0	51.4	44.5
C1907	290	8	240	30	55.5	54.5	50.8
C1908	380	10	210	20	22.6	58.8	44.1
C1909	500	9	430	20	23.9	47.2	44.6
C1910	380	12	220	20	20.9	53.7	48.0
C1911	200	19	460	100	72.9	72.4	39.2
C1912	150	48	2690	210	125.0	120.0	42.2
C1913	180	70	550	80	47.4	49.9	42.6

Table IV: Chemical Analysis of LEU-7Mo powder (continue)

Unit : μg/g *wt%

Batch	Cu	B	Cd	Co	Li	Zn	Mo*
C1901	14.2	<5	<5	<5	<5	<5	6.83
C1902	13.6	<5	<5	<5	<5	16	6.93
C1903	14.9	<5	<5	<5	<5	<5	7.13
C1904	<5	<5	<5	<5	<5	<5	7.11
C1905	<5	<5	<5	<5	<5	5.7	7.08
C1906	<5	<5	<5	<5	<5	<5	7.29
C1907	<5	<5	<5	<5	<5	<5	7.07
C1908	16.1	<5	<5	<5	<5	<5	7.21
C1909	14.5	<5	<5	<5	<5	<5	7.20
C1910	15.1	<5	<5	<5	<5	<5	7.13
C1911	<5	<5	<5	<5	<5	<5	7.30
C1912	<5	<5	<5	<5	<5	<5	7.17
C1913	<5	<5	<5	<5	<5	<5	7.18

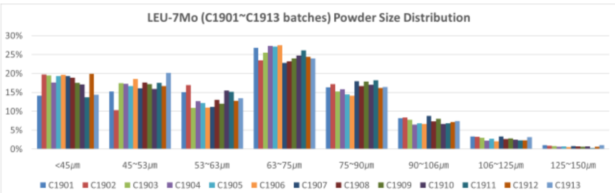

Fig. 6. LEU-7Mo powder size distribution

Powder size distribution analysis is presented in Fig. 6. LEU-7Mo powder with diameter under 150 ㎛ accounts for 99.00 wt.% and the powder with diameter between 63~75 ㎛ is the highest proportion with 25.15 wt.%. After a packing process presented in Fig. 7, KAERI transported 39 kg of LEU-7Mo powder to CERCA, France in 2020. On Oct. 2021, remaining 3.35 kg of LEU-7Mo powder will be transported to CERCA to fabricate the KUCA core fuel assemblies.

Fig. 7. LEU-7Mo Powder Packing Process

4. Conclusion

Since the 2012 NSS agreement, KAERI has actively participated in the international cooperation projects for minimizing HEU fuel. KAERI fabricated total 155.64 kg of LEU-7Mo powder in 2013 and 2019 using the atomization technology. It is advanced and key technology to fabricate LEU-7Mo powder in commercial scale. If these LEU conversion projects for HPRRs and KUCA are successfully completed, KAERI will become one of main suppliers for LEU-7Mo powder and take a leading role in the nuclear non-proliferation policy.

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