

〈Technical Note〉

A STUDY ON OXIDATION TREATMENT OF URANIUM METAL CHIP UNDER CONTROLLING ATMOSPHERE FOR SAFE STORAGE

CHANG-KYU KIM*, CHUL-GOO JI, SANG-OH BAE, YOON-MYEOUNG WOO, JONG-GOO KIM and YEONG-KEONG HA

Korea Atomic Energy Research Institute

150, Deokjin-Dong, Yuseong-Gu, Daejeon, 305-353, Korea

*Corresponding author. E-mail : Ckkin2@kaeri.re.kr

Received August 16, 2010

Accepted for Publication March 14, 2011

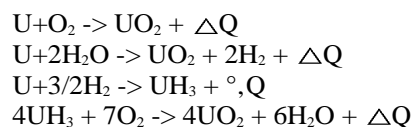
The U metal chips generated in developing nuclear fuel and a gamma radioisotope shield have been stored under immersion of water in KAERI. When the water of the storing vessels vaporizes or drains due to unexpected leaking, the U metal chips are able to open to air. A new oxidation treatment process was raised for a long time safe storage with concepts of drying under vacuum, evaporating the containing water and organic material with elevating temperature, and oxidizing the uranium metal chips at an appropriate high temperature under conditions of controlling the feeding rate of oxygen gas. In order to optimize the oxidation process the uranium metal chips were completely dried at higher temperature than 300 °C and tested for oxidation at various temperatures, which are 300 °C, 400 °C, and 500 °C. When the oxidation temperature was 400 °C, the oxidized sample for 7 hours showed a temperature rise of 60 °C in the self-ignition test. But the oxidized sample for 14 hours revealed a slight temperature rise of 7 °C representing a stable behavior in the self-ignition test. When the temperature was 500 °C, the shorter oxidation for 7 hours appeared to be enough because the self-ignition test represented no temperature rise. By using several chemical analyses such as carbon content determination, X-ray deflection (XRD), Infrared spectra (IR) and Thermal gravimetric analysis (TGA) on the oxidation treated samples, the results of self-ignition test of new oxidation treatment process for U metal chip were interpreted and supported.

KEYWORDS : U Metal Chip, Storage, Oxidation, Atmosphere Control, Self-ignition Test, Chemical Analysis, Carbon Content Analysis, XRD Diffraction, TGA, Infra-red Spectra, Acceptable Condition

1. INTRODUCTION

At KAERI, depleted uranium metal has long been used as a surrogate material for nuclear metallic fuel development as well as a raw material for gamma radioactive ray shields. Whenever a uranium metal ingot is cut into pieces or machined, uranium metal chips are automatically generated. In general, uranium metal in large pieces is not pyrophoric at room temperature [1]. However, uranium chips are liable to ignite due to their large specific surface area. Reportedly, uranium metal powder of about 10 mm size can ignite at lower than 100 °C [2]. Oxidation of a uranium metal surface forms a uranium oxide film and then proceeds further by penetration of oxygen through the film. The oxidation rate increases exponentially with temperature but actually is controlled by the penetration rate of oxygen. When the oxidation layer is thick or the temperature is relatively high, the oxide layer is exfoliated from unsound and weak areas.

The reaction rate fluctuates according to the exfoliation rate. In general, as the temperature increases the oxidation rate gets higher. When the temperature is higher than 625 °C, the oxidation film spalls off with powder and it accelerates the oxidation rate [3]. When uranium metal is stored at 100 % relative humidity in normal air, it has been reported that the corrosion rate is greater than that in dry air or less than 90 % relative humidity air by approximately an order of magnitude [4]. When a uranium chip is wetted with water, it becomes more ignitable as a result of uranium hydride, which is a reaction product of uranium metal and water, as shown in the following reactions [5].



Accordingly the safe storage of the above uranium chip would necessitate a sort of inert atmosphere or a

passivation measure on the surface of the uranium chip. In some cases, an immersion method in mineral oil has been applied because oil can prevent a uranium chip from contacting air or water. It is known that the Y-12 plant in the USA has used a water immersion method without any problems [6]. Presumably the reaction rate is very strongly dependant on temperature, so that enough water can keep uranium chips at low temperature. At KAERI, all kinds of uranium chips have been stored by the immersion in water.

It is thought that one measure for perfect safe storage could be an oxidation treatment of uranium chips, which is a kind of stabilization treatment. In general, uranium chips ignite in the air and then vigorously burn generating flames and smoke containing dust induced from the contaminated organic inclusions. For collecting the dust and preventing the contamination of the environment, a lot of work as well as some complex equipment are required. In order to avoid this difficulty, steady oxidation under a controlling atmosphere has been considered. At KAERI, uranium scraps of chip shape are stored under water. The concept of the new steady oxidation process consists of evacuating the oxidation chamber, evaporating the containing water and organic material by elevating the temperature, and oxidizing the uranium chip at an appropriate high temperature while controlling the feeding rate of oxygen gas. New equipment was designed on the basis of the above concept and manufactured by local industry. In order to optimize the oxidation process parameters, some oxidation tests for a uranium chip were done for various temperatures and holding times. The oxidized product of the uranium chip was analyzed and assessed in the safe storage.

2. EXPERIMENTS

2.1. Sampling U Chips for Experiments

A chip from cutting a uranium metal ingot by band-saw is observed to be plate-like and longish as in Fig.1. The chip size has been measured to be between 200 to

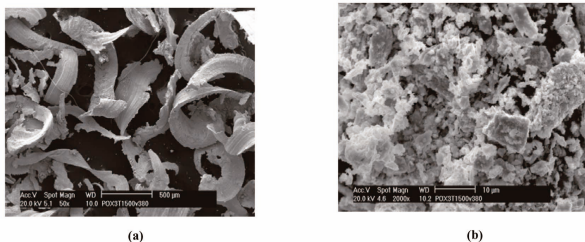


Fig. 1. Morphologies of Uranium Chips: (a) Chips Generated from Cutting a Uranium Metal Ingot by Band-saw and (b) Chips under a Long-time Storage in Water

400 μm . When a uranium chip is stored by immersion in water, it reacts with water and then becomes porous.

A chip from machining uranium metal parts by lathe, which is called as turnings, is very long. The chip size from machining by a lathe is generally larger than that from band-sawing. The portion of band-saw chips is more than 50% of the total uranium chips under storage at KAERI. Because band-saw chips have more risk for ignition, oxidation treatment for them is under way as a priority. Samples for this study were taken from band-saw chips immersed in water.

2.2 Oxidation Experiments

The oxidation experiments for the uranium chips were performed using newly designed and manufactured equipment, which is able to control the atmosphere available for vacuum and oxygen and the temperature up to 500 $^{\circ}\text{C}$. The temperatures of the oxidation treatments were performed at 300 $^{\circ}\text{C}$, 400 $^{\circ}\text{C}$, and 500 $^{\circ}\text{C}$. When the chips immersed in water in a plastic barrel are taken, they seem like a sludge containing water. Accordingly, before oxidation treatment, the sludge-like chips were dried by evacuating the air in the oxidation chamber and elevating the temperature up to oxidation temperature condition for 7 hours. The chip was charged in a rotating drum located in the oxidation chamber. There are some baffles on the inside wall of the drum. The charged sludge-like chips was jumbled so that oxygen contact with them became more efficient. After the water contained in the sludge-like chips was removed, the oxidation chamber was heated up to the intended temperature after evacuating the chamber and then oxygen gas was fed with a slow-rate up to 650 torr. And then this oxidation condition was maintained for 7 hours in one day. Oxygen gas was put in the almost completely cooled oxidation chamber for a kind of self-ignition test of the uranium chips while checking the temperature of the chamber. One additional oxidation treatment, in which the oxidation time at the elevated temperature was 7 hours, was done in order to stabilize the uranium chips more completely. A self-ignition test was done in the above way to check the stability of the uranium chips with a viewpoint of safe storage.

2.3 Chemical Analysis for Various Oxidized Samples of U Chips

After each step of oxidation treatment, a sample was taken from the uranium chips under processing. Some chemical analyses were performed for the samples. The content of uranium and carbon in the samples was measured individually by Induced Coupled Plasma - Atomic Emission Spectroscopy (ICP-AES, Jobin Yvon ULTIMA 2C) and a Carbon analyzer (ELTRA CS800). An X-ray diffraction analysis was carried out for the oxidized samples.

2.4 Thermo-gravimetric Analysis

Firstly, the weight losses were measured in an inert Ar gas flow at 1 atm. and temperatures ranging from 20 °C to 600 °C with a heating rate of 1 °C/min using a Setaram TGA-92 thermo-analyzer. And then the samples were repeatedly heat-treated in an air atmosphere in the same way as above. The weight gains from oxygen during heat-treatment were measured and then compared with the weight of the samples previously heat-treated under the Argon atmosphere.

2.5 Identification of the Chemical Structure in the Heat-treated Samples Using Infrared Spectra

Infrared spectroscopy provides information on the chemical bonding character of compounds and so it can be used for the identification of the chemical structure of a complex U-O system. The sample #4 among 10 samples was chosen for FTIR measurement, because it was in a well dried state when treated at a relatively low temperature, 300 °C, which is not high enough to burn all organic compounds. So organic compounds contained in the sample could be identified from the Infrared spectra. In order to identify the chemical structure in the sample, the sample was heat-treated in several ways, at 420 °C and 650 °C in air, as well as 650 °C in argon. The infrared spectra were measured in the range of 4000 to 400 cm⁻¹ at room temperature.

3. OXIDATION RESULT

3.1 Oxidation at 300 °C

Sludge-like uranium chips of 15.56 kg were charged in the oxidation chamber. The chamber was evacuated up to about 40 torr and then heated up to 100 °C for one hour. This drying treatment was done for 7 hours. A self-ignition test was conducted for the drying-treated uranium chips, which were cooled to almost room temperature. With no change in the chamber temperature no self-ignition was assumed to happen. After disassembling the chamber the drum containing the chips was weight-measured. The weight change was 2.36 kg. The portion of weight loss for total charging weight was about 15%. It is thought that this drying condition would not be enough to remove the water in the sludge-like U chips completely.

The uranium chips, which were dried at 100 °C under evacuation, were further dried at 300 °C under evacuation. It took about 1.5 hours to elevate temperature up to 300 °C. This drying treatment was done for 6.5 hours. A self-ignition test was performed while feeding oxygen gas with 7.0 ml/min and measuring the drum temperature. The oxygen pressure in the chamber was controlled between 550 to 650 torr. The temperature rose from 11 °C to 65 °C gradually over 75 minutes from the presumed

oxidation reaction as shown in Fig. 2. The oxygen pressure increased to maximum pressure for about 15 minutes.

The oxidation reaction rate was assumed to be much slower than the expected rate. The reason could be attributed to insufficient contact of the chips with oxygen or to the barrier of the oxidized layer of the chip surface. The weight of the uranium chip decreased to 12.42 kg when drying at 300 °C. The loss portion of weight from the original charging weight was about 20.2%. After drying the sludge-like uranium chips at 300 °C it was visually observed to be powder-like without any stickiness.

After a self-ignition test, the chips were heated to 300 °C for one hour in an oxygen atmosphere of about 600 torr and the oxidation condition was maintained for 7 hours. After cooling to room temperature, a self-ignition test was performed in the above way. The temperature increased more slowly than it did for the chip dried at 300 °C from 8 °C to the maximum temperature of 18 °C over about 75 minutes as in Fig. 2. The weight of the remaining uranium



Fig. 2. Self-ignition Test after Drying Sludge-like Uranium Chips for 6.5 Hours at 300 °C under Vacuum

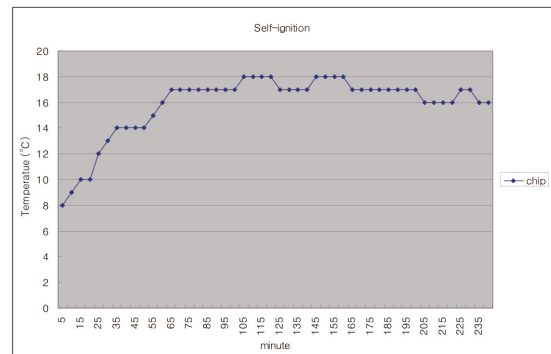


Fig. 3. Self-ignition Test after Oxidation for 7 Hours under Oxygen Atmosphere at 300 °C

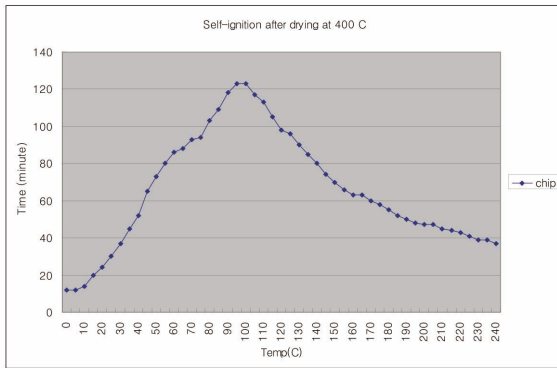


Fig. 4. Self-ignition Test after Drying for 7 Hours under Vacuum Atmosphere at 400 °C

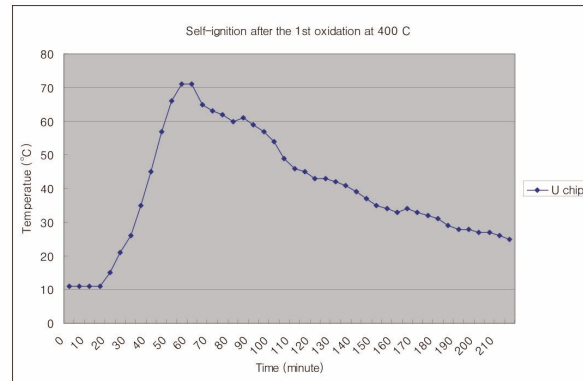


Fig. 5. Self-ignition Test after Oxidation for 7 Hours at 400 °C

chips showed a slight lost from 12.46 kg to 12.36 kg. The portion of the lost weight for the initial weight is very small at 0.38%. The weight loss portion for drying and oxidizing was 20.6%.

After a self-ignition test for the chip had been done for the 1st oxidation treatment, the chip was additionally oxidized at 300 °C for about 7 hours. As above, a self-ignition test was conducted in the same way. The temperature of the U chips increased to 34 °C over 60 minutes. The weight of the oxidized product was measured to be 12.24 kg. The additional loss by the 2nd oxidation treatment versus the initial input weight was 0.77%.

3.2 Oxidation at 400 °C

Uranium chips of 15.32 kg were taken for an oxidation experiment at 400 °C. It took about 1.0 hours to elevate the temperature up to 400 °C. In order to remove the water from the sludge-like chips, they were held for 7 hours at 400 °C while evacuating the chamber by a vacuum pump. The inside pressure was maintained at 30~40 torr. On self-ignition test, the temperature rose from 12 °C to 123 °C gradually over 95 minutes as shown in Fig. 4.

The weight of the uranium chip decreased from 15.32 kg to 10.8 kg, which is 70.5 % for the initial loading weight of the chip. The loss portion is corresponded to 29.5 %, which is bigger than the loss portion of 20.2 % for drying at 300 °C.

After a self-ignition test, the chips were heated to 400 °C for one hour in an oxygen atmosphere of about 600 torr and the oxidation condition maintained for 7 hours. A self-ignition test showed that the temperature increased from 11 °C to 71 °C over about one hour. The temperature increase of 60 °C in the self-ignition test after the chips were firstly oxidized is much less than that of the chips that were only dried. The loss portion of the 1st oxidation at 400 °C was 0.72 % of the initially loaded U chip. It is a

little more than that of the 1st oxidized U chips at 300 °C. The total weight loss for drying and the 1st oxidation treatment at 400 °C was 30.2%, which is much greater than that for 300 °C.

After a self-ignition test for the chips done for the 1st oxidation treatment, the chips were additionally oxidized at 400 °C for about 7 hours. As above, a self-ignition test was conducted in the same way. The temperature of the U chips increased from 13 °C to 20 °C over 45 minutes. The additional loss by the 2nd oxidation treatment for the initial input weight was 0.71%. The total weight loss portion for the initially loaded chips regarding the whole treatment at 400 °C was about 30.9%, which is greater than 21.3 for the whole treatment at 300 °C. It is assumed that the volatile materials in the chips would be more efficiently removed by increasing the temperature from 300 °C to 400 °C.

3.3. Oxidation at 500 °C

Uranium chips of 14.01 kg were loaded in an oxidation chamber for an oxidation experiment at 500 °C. In order to remove the water from the sludge-like chips the chips were heated up to 500 °C for about 1.0 hour and held for 7 hours at 400 °C while evacuating the chamber by a vacuum pump. The vacuum degree of the inside pressure was formed at the relatively higher pressure of 220 ~240 torr a while after the temperature had risen up to 500 °C. It is thought to be due to strong evaporation from the higher temperature. After that, the pressure decreased gradually to 60 torr after 2 hours had passed.

On a self-ignition test, the temperature increased from 11 °C to 98 °C gradually over about 100 minutes as shown in Fig. 6. When comparing with the chips dried at 400 °C, the peak temperature of the self-ignition test for the chips at 500 °C was lower than that at 400 °C. However the temperature of the chips decreased more slowly. The

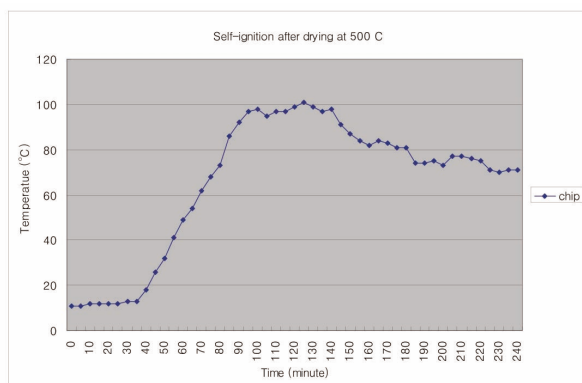


Fig. 6. Self-ignition Test after Drying for 7 Hours under Vacuum Atmosphere at 500 °C

chip weight loss after drying in the 500 °C self-ignition test was measured to be 3.72 kg, which is 26.6% of initial loading. The loss portion for 500 °C is a little less than that for 400 °C.

After a self-ignition test, the chips were heated to 500 °C for one hour in an oxygen atmosphere of about 600 torr and the oxidation condition was maintained for 7 hours. A self-ignition test showed that the temperature had not changed. The weight loss portion of the 1st oxidation at 500 °C was 1.8 % for the initially loaded U chips. The total weight loss portion was 28.3%, which is less than that for 400 °C. The 2nd oxidation treatment and a self-ignition test were done in the above way. There was no temperature change on the self-ignition test. In the case of 500 °C, it is thought that one oxidation treatment could be sufficient. The weight loss in the 2nd oxidation treatment was almost negligible at 0.03 kg, which is 0.2% of the initial loaded chip weight. The total weight loss portion for the initial loading was 28.6%. Even though the oxidation for the U chip at 500 °C is more efficient than that at 400 °C, the weight loss portion appeared to be smaller. Presumably this result can be attributed to the different water content of the sludge-like chips.

4. ANALYSIS

4.1 Chemical Analysis

Table 1 is the result of a chemical analysis of U and C for various treated samples. The carbon contents of samples treated at a temperature above 400 °C are shown to be very low at less than 1.0 wt%. However the carbon contents of samples (#3, #4) treated around 300 °C were shown to be large at more than 8.0 wt%. Comparing the carbon content of sample #4 with sample #3, the results are almost the same, even though sample #4 was treated 7

Table 1. Chemical Analysis of U and C for Various Treatments

Treatments	U (%)	C (%)
#1 (dried at vacuum, 100 °C for 7 hours)*	-	-
#2 (dried at vacuum, 300 °C for 7 hours)*	-	-
#3 (treated with oxygen, 300 °C for 7 hours)	47.9	8.9
#4 (treated with oxygen, 300 °C for 14 hours)	67.8	8.5
#5 (dried at vacuum, 400 °C for 7 hours)	72.0	1.5
#6 (treated with oxygen, 400 °C for 7 hours)	73.4	0.8
#7 (treated with oxygen, 400 °C for 14 hours)	71.4	0.9
#8 (dried at vacuum, 500 °C for 7 hours)	75.3	0.8
#9 (treated with oxygen, 500 °C for 7 hours)	76.1	0.4
#10 (treated with oxygen, 500 °C for 14 hours)	78.3	0.3

*The samples #1, #2 were excluded in the analysis because the samples contained too much water due to insufficient drying.

hours longer than sample #3 at 300 °C. The carbon content of the samples at 400 °C was dramatically reduced to about 1 wt%. When the temperature increased from 400 °C to 500 °C, the carbon content of the samples decreased further to about half value. It is thought that temperature is an important factor for removing organic materials and the temperature should be no lower than 400 °C to remove most organic material in the sample. For both temperatures of 400 °C and 500 °C the carbon content of the dried samples decreased by half through oxidation treatment for 7 hours. However, an additional oxidation treatment of the above samples for 7 hours showed little carbon reduction for both temperatures. From the above results, it is thought that 7 hours for the oxidation should be enough.

The uranium content of samples appeared to increase adversely with respect to a decrease of carbon. The very low uranium content of 47.9 % in sample #3 seems to come from insufficient drying due to a low temperature and short drying time. In general, the uranium content in the samples was shown to increase with the temperature, 67.8 % at 300 °C, 71.4–73.4 wt% at 400 °C, and 75.3–78.3 wt% at 500 °C. The remaining residue after oxidation treatment at 300 °C and 400 °C was observed to be black. In the oxidation treatment at 500 °C the residue was shown to be a little yellowish. The allowable oxidation condition from a viewpoint of automatic ignition and firing is considered to be drying for 7 hours at 400 °C and oxidizing for longer than 7 hours at 400 °C, which corresponds to treatment #7.

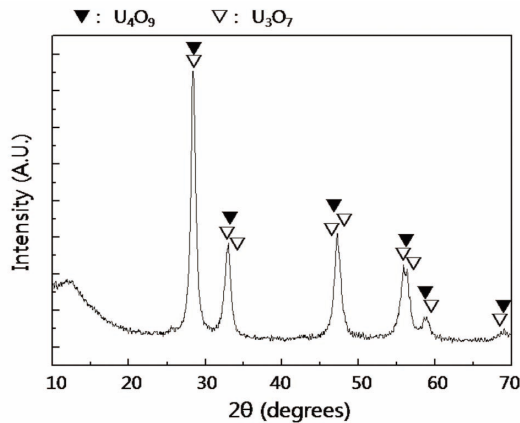


Fig. 7. XRD Patterns of Sample #7 Treated with Oxygen, at 400 °C for 14 hours

Fig. 7 is the result of an XRD analysis for sample #7. Sample #7 was found to be mixed phases of U_4O_9 and U_3O_7 from the XRD patterns which are chemically stable in air.

4.2 Thermal Gravimetric Analysis (TGA)

Thermal gravimetric analysis on the oxidation treated samples (#3 - #10) were performed by consecutive heating, first in argon atmosphere and second in air, and the results are shown in Fig. 8.

The weight losses in the TGA curves from the first heating in argon atmosphere are thought to be caused by only volatile materials like water and organic materials except uranium components, because uranium components in the samples should be metal or oxide forms which are stable in argon atmosphere without further oxidation. So the weight variation curves from first the heating in argon atmosphere give an information about the amounts of organic materials retained in the oxidation treated samples. The weight losses for the samples #3 and #4 were large compared to those of the other samples. And the weight losses decreased little by little for the samples from #5 to #10 and the weight loss of sample #10 is almost negligible. This gravimetric analysis results are in accord with the results of the chemical analysis as shown in Table 1. It is confirmed again that the oxidation treatment conditions of #3 and #4 are insufficient and the oxidation treatment condition of #10 is enough to remove almost all organic materials.

The weight variation curves from the first heating in argon show plateaus above 450 °C regardless of oxidation treated samples. It means that the samples would attain a state without further volatilization or decomposition at a temperature near 450 °C. From this result, it can be thought that the optimum treatment temperature for entire removal

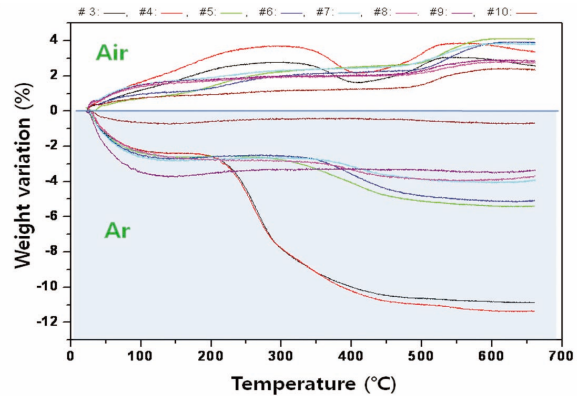


Fig. 8. Measurement of Weight Variation by Consecutive Heating, First in Ar and Second in Air, of the Oxidation Treated Samples (#3 - #10)

of organic materials of uranium metal chip samples would be near 450 °C

The weight gains in TGA curves for the consecutive heating in air after heating in argon are thought to be presumably due to oxidation of the remaining U metal or uranium oxides with low valence.

The weight losses shown at the temperature range, 350 °C to 400 °C of the curves for the #3, #4 would be caused by decomposition of some materials in the air which were still retained even in the preceding heating in argon. The weight variation curves of the second heating in air show plateaus above 500 °C. It means that all the samples could be converted to chemically stable U_3O_8 form near 500 °C in air. And so the oxidation condition of near 500 °C should be enough to obtain the stability from self-ignition and firing.

Two final state weights, W_B and W_A , by heating up to 650 °C in argon and air, which are from thermal gravimetric analysis, are included in Table 2. Assuming that final product heating up to 650 °C in air is U_3O_8 form, the average oxidation states (UO_x) of U in the oxidation treated samples (#5 - #10) can be calculated using two final state sample weights. The calculation for #3, #4 is excluded, because the W_B 's for the #3, #4 would still include volatile materials other than uranium materials. In Table 2, the values of x of UO_x in Table 2 have a tendency to increase with treatment temperature and time, which generally gives higher stability with respect to oxidation.

4.3 Analysis Results by Infrared Spectra for Oxidized Samples

The results of Infrared spectra for sample #4 are shown in Fig. 9. The spectra for the initial state show peaks in the 2800-3000 cm^{-1} region, but in contrast the peaks were

Table 2. Weight Loss and Again by Heating to 650 °C in Argon and Air and Calculation of Average Oxidation States of Uranium in Oxidation Treated Samples

	Argon			Air		Calculated average oxidation states of uranium
	W _A [*] (mg)	W _B ^{**} (mg)	(W _B -W _A)/W _A x 100 (%)	W _C ^{***} (mg)	(W _C -W _B)/W _B x 100 (%)	
#3	26.3	23.8	-9.43	24.3	2.06	-
#4	22.1	20.1	-8.97	20.6	2.34	-
#5	27.7	26.8	-3.29	27.7	3.55	UO _{2.10}
#6	21.3	20.7	-2.68	21.3	2.89	UO _{2.17}
#7	17.6	17.5	-0.96	17.9	2.29	UO _{2.28}
#8	16.1	15.8	-1.86	16.2	2.15	UO _{2.24}
#9	14.4	14.4	0	14.6	1.60	UO _{2.43}
#10	19.7	19.7	-0.1	20.0	1.88	UO _{2.41}

W_A^{*} : Initial weight of the samples

W_B^{**} : Final weight of the samples after heating to 650 °C in argon atmosphere

W_C^{***} : Final weight of the samples after heating to 650 °C in air atmosphere

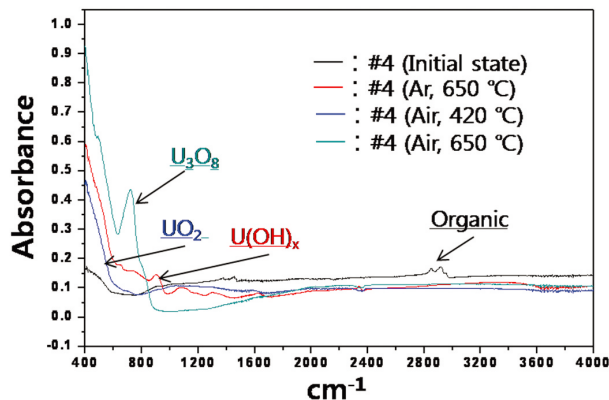


Fig. 9. Characterization of Species by IR Spectra after Consecutive Heating of the Sample #4 in the Order of, 1) Ar, 650 °C, 2) Air, 420 °C, 3) Air, 650 °C

absent in the spectra for the sample which was heated at 650 °C in Ar. From this absence of peaks, it can be deduced that the peaks are attributed to organic compounds which can evaporate by heating at 650 °C in Ar. The peaks in the region 850-1600 cm⁻¹ for the sample heated at 650 °C in Ar are not easy to identify, but they are thought to be caused by uranium hydroxide compounds [U(OH)_x][6], since peaks of uranium oxides (UO_x) in this region have not been found in the literature and the samples have been stored in water for a long time.

The spectra for the sample heated at 420 °C in air

shows a typical feature of uranium dioxides (UO_{2+x}) but in contrast it does not show the peaks in the 850-1600 cm⁻¹ region. The spectra for the sample heated at 650 °C in air shows a peak of 715 cm⁻¹, which is a typical U₃O₈ peak.

5. CONCLUSION

The self-ignition test using the new oxidation treatment process showed the results of temperature rise, of 60 °C for 7 hours oxidation, of 7 °C for 14 hours oxidation at 400 °C and no temperature rise for 7 hours oxidation at 500 °C. From these temperature rise results, the condition of the oxidation treatment for 7 hours at 500 °C is thought to be enough as a condition for safe storage of uranium chips.

The carbon content results by chemical analysis show that organic materials of uranium chips were removed to a few % by oxidation treatments at 400 °C and removed further to tiny amount by oxidation treatments at 500 °C. And, according to the thermal gravimetric analysis, the optimum temperature for entire removal of organic materials of uranium metal chip samples was known to be near 450 °C

From the IR spectra, X-ray deflection measurements and the thermal gravimetric analysis, it is known that the major phases of uranium of uranium chip samples are U₄O₉ and U₃O₇ when treated at 400 °C and U₃O₈ when treated at the temperature higher than 500 °C, which are chemically stable in air.

Accordingly the optimum condition for the oxidation treatment for U metal chips stored under water are concluded to be at the temperature, near 500 °C and the duration longer than 7 hours.

REFERENCES

- [1] Charles W. Solbrig et al. "Pyrophoricity of Uranium in Long-term Storage Environments", Argonne National Laboratory
- [2] In-Hyung Moon, "Powder Metallurgy", 1981, p49
- [3] "A Study on the Oxidation Behavior of Uranium", KAERI/TR-987/98, Korea Atomic energy Research Institute
- [4] "Assessment of enrichment Uranium Storage Safety Issues at the Oak Ridge Y-12 Plant" Y/014/R4, 1996, Oak Ridge Y-12 Plant
- [5] "Primer on Spontaneous Heating and Pyrophoricity", DOE Handbook, "DOE-HDBK-1081-94", 1994, Dec.
- [6] "Statement of Work, Treatment and disposal of uranium and thorium chips at various department of energy sites", Nov. 8, 2001
- [7] V. Baran, L. Sourkova, J. Spalova, J. Radioanal. Nucl. Chem., Letters 95 (1985) 331-338