

INFORME **DFN/RA-09/SP-26**

REF. EXTERNA

INFLUENCE OF FABRICATION ROUTE ON Cr-DOPED UO_2 OXIDATION (IONMAT PROJECT. SUBTASK 2.3)

DIVISIÓN DE FISIÓN NUCLEAR

Ciemat Centro de Investigaciones
Energéticas, Medioambientales
y Tecnológicas

CSV : GEN-b93b-456f-f1f7-5689-4edb-9dcc-2362-4186

DIRECCIÓN DE VALIDACIÓN : <https://run.gob.es/hsbGNz2yTj>



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 1 DE 17
	REF. EXTERNA	REVISIÓN 0

TITULO: Influence of fabrication route on Cr-doped UO_2 oxidation (IONMAT project. Subtask 2.3)

AUTORES: A. Milena-Pérez, N. Rodríguez-Villagra, J. M. Elorrieta, S. Fernández-Carretero, H. Galán

ABSTRACT:

Cr-doped UO_2 is one of the shortest-term Accident-Tolerant Fuel (ATF) concepts. Among other improvements, its design aims to provide enhanced safety margins in case of abnormal operation. But also, to provide delayed corrosion mechanisms compared to standard UO_2 , what becomes especially relevant for different spent fuel storage/disposal scenarios envisaged in the back-end of the nuclear fuel cycle. Here, a set of Cr-doped UO_2 pellets obtained by two different methods (dry route and wet co-precipitation) are oxidized in air, and the results compared as a function of the fabrication route. The results show that the production method plays a more important role than the concentration of dopant itself.

	NOMBRE	FIRMA	FECHA	
Preparado por:	A. Milena-Pérez			
Revisado por:	N. Rodríguez-Villagra			
Conf por A. C.:	S. Fernández			FECHA DE EMISIÓN
Aprobado por:	E. González Romero			



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 2 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

Index

1.	INTRODUCTION	5
2.	MATERIALS AND METHODS.....	7
3.	RESULTS	9
	3.1. TGA CURVES.....	9
	3.2. O/M curves	10
	3.3. DSC curves	13
4.	SUMMARY OF RESULTS	15
5.	ACKNOWLEDGMENTS.....	16
6.	REFERENCES.....	17



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 3 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

Index of tables

Table I Calculated stoichiometry of Cr-doped UO_2	8
Table II Calculated values from TGA curves showed in Figure 2 and Figure 3. The uncertainty associated with transition temperatures obtained from derivative analyses is estimated to be $\pm 2-5$ °C, while the uncertainty in O/M calculations is within the experimental precision of the thermobalance.	12
Table III Calculated values from DSC curves of co-precipitated undoped and Cr-doped UO_2 during oxidation in air (21% O_2) shown in Figure 4. Uncertainty for each parameter lies around 1%, taking into account the precision of the instrument.	14



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 4 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

Index of figures

Figure 1. Visual pulverization of the undoped UO ₂ pellet (obtained by dry route) after being oxidized up to 700 °C at 21% O ₂	9
Figure 2 Oxidation curves of the ATFs studied from RT to 700 °C in air (21% O ₂). A) Undoped and Cr-doped UO ₂ obtained by dry route; B) undoped and Cr-doped UO ₂ obtained by co-precipitation route.....	10
Figure 3 O/M curves of the ATFs studied from RT to 700 °C in air (21% O ₂). A) Undoped and Cr-doped UO ₂ obtained by dry route; B) undoped and Cr-doped UO ₂ obtained by co-precipitation route.....	11
Figure 4 DSC curves of the ATFs studied from RT to 550 °C in air (21% O ₂) for undoped and Cr-doped UO ₂ obtained by co-precipitation route.	13



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 5 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

1. INTRODUCTION

Accident Tolerant Fuels (ATFs) are being developed to improve the safety margins of current light water reactors under both normal and accident conditions. Among the different ATF concepts, chromium-doped UO_2 has attracted considerable interest because the addition of small amounts of Cr_2O_3 promotes grain growth during sintering, improves pellet densification and may enhance in-reactor fuel performance [1-3]. However, the influence of chromium addition and fabrication route on the oxidation behavior of UO_2 remains not enough understood.

The oxidation of UO_2 is a key phenomenon in the nuclear fuel cycle because it may occur during fuel fabrication, transport, interim storage, long-term storage and accident scenarios involving air ingress. Oxidation results in the progressive transformation of UO_2 into hyperstoichiometric oxides, $\text{U}_4\text{O}_9/\text{U}_3\text{O}_7$ and ultimately U_3O_8 . The formation of U_3O_8 is accompanied by a significant volume expansion that causes pellet cracking, fragmentation and pulverization, potentially affecting fuel integrity and radionuclide release. Therefore, understanding the oxidation behavior of advanced UO_2 -based fuels is important from both operational and safety perspectives [4, 5].

Previous studies have shown that chromium additions modify the microstructure of UO_2 by increasing grain size [1]. These microstructural changes may affect oxygen diffusion pathways and consequently oxidation kinetics. Nevertheless, the influence of chromium concentration is often difficult to separate from the effect of the fabrication method, since different processing routes cause different grain structures and dopant distributions.

For sintered UO_2 pellets and oxidized in air (21% O_2), the formation of U_3O_7 and U_3O_8 occurs at a relatively limited temperature interval. As a result, the thermogravimetric curves exhibit a single well-defined oxidation step associated with oxygen incorporation into the UO_2 lattice [6-8]. This process is initiated by surface reactions occurring preferentially along grain boundaries, accompanied by crack formation on the grain surface [8], which exposes fresh UO_2 to oxygen. As oxidation advances, the formation of U_3O_8 leads to the detachment of fine powder from the pellet surface [7-9].

Within the framework of the IONMAT project, Cr-doped UO_2 pellets were manufactured using two different routes: a conventional dry powder process [2] and a wet co-precipitation method [3]. These materials constitute an excellent model system for



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 6 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

evaluating the relative importance of dopant concentration and fabrication route on UO_2 oxidation behavior. Therefore, the objective of this work is to compare the oxidation behavior of undoped and Cr-doped UO_2 pellets manufactured by dry and wet routes under oxidizing conditions (21% O_2). Thermogravimetric analysis (TGA), oxygen-to-metal ratio calculations (O/M) and differential scanning calorimetry (DSC) were used to investigate oxidation mechanisms, oxidation kinetics and final oxidation states. Particular attention is given to the influence of the fabrication route on oxidation resistance, as evaluated through onset temperatures, maximum oxidation rates, oxidation peak temperatures and associated reaction enthalpies. Based on the results obtained, it is hypothesized that the fabrication route has a stronger influence on oxidation kinetics than chromium concentration itself, owing to the microstructural differences generated during pellet manufacturing.



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 7 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

2. MATERIALS AND METHODS

UO₂ pellets doped with 600, 1000, and 6000 ppm Cr₂O₃ prepared by the dry route [2], and pellets doped with 600, 1000, and 3000 ppm Cr₂O₃ prepared by the co-precipitation route [3], were used to compare oxidation behavior. The fabrication routes and a complete characterization of these samples were reported previously [1-3]. Synthetic air was provided by Air Liquide, with a composition of 20±1% O₂, being the rest N₂ (named as 21% O₂ in the rest of the document). A certified purity higher than 99.999% is guaranteed by the supplier.

The oxidation experiments were carried out by thermogravimetric analyses, using a TGA Q50 thermobalance (TA Instruments) for pellets from dry route and a TGA Q550 thermobalance (TA Instruments) for pellets from wet method. The reactions were done using an airflow at a constant rate of 60 ml·min⁻¹. The instruments were calibrated in both, temperature of magnetic standards (Curie point, ASTM E-1582) and weight. The oxidation of the pellets was conducted by heating the samples from room temperature up to 700 °C with a linear heating rate of 10 °C·min⁻¹. The mass gain curves were analyzed with the software Universal Analysis and TRIOS (TA Instruments). From the TGA curves, several kinetic parameters were extracted to compare oxidation behavior. The oxidation onset temperature (T_{onset}) was determined from the intersection between the baseline and the tangent at the maximum slope of the oxidation step. The temperature of maximum oxidation rate (T_{max}) and maximum oxidation rate were obtained from the maximum of the first derivative curve (dm/dt). The final O/M ratio was calculated from the mass measured during TGA assuming conservation of the cation (U+Cr) during oxidation. The nominal sample composition U_{1-x}Cr_xO₂ was first obtained from the Cr₂O₃ theoretical content (see Table I). Then, the oxygen incorporation was determined from the relative mass increase and converted into the final O/M ratio using the corresponding molar mass of each composition. These parameters provide a quantitative comparison of oxidation resistance and oxidation kinetics among the different materials.



Ciemat DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 8 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

Table I Calculated stoichiometry of Cr-doped UO_2 .

ppm Cr_2O_3	wt.% Cr_2O_3	x in $\text{U}_{1-x}\text{Cr}_x\text{O}_2$	Molar mass in $\text{U}_{1-x}\text{Cr}_x\text{O}_2$ ($\text{g}\cdot\text{mol}^{-1}$)
0	0	0.0000	270.03
600	0.06	0.002	269.63
1000	0.1	0.004	269.37
3000	0.3	0.011	268.06
6000	0.6	0.021	266.12

DSC measurements were performed using a DSC 25P instrument (TA Instruments) where experiments can be performed under static or dynamic purge. In this case, dynamic purge under 1 atm of synthetic air pressure was selected. The experiments were conducted under the same conditions as the thermogravimetric analyses, using synthetic air and a heating rate of $10\text{ }^\circ\text{C}\cdot\text{min}^{-1}$. Samples were heated from room temperature up to $550\text{ }^\circ\text{C}$ (maximum of the instrument) in order to identify the thermal events associated with the oxidation process. The enthalpy values associated with the oxidation were estimated using the “Peak Integration” tool implemented in the TRIOS software (TA Instruments). The area under each exothermic peak was numerically integrated by the software and normalized to the sample mass, providing the reaction enthalpy in $\text{J}\cdot\text{g}^{-1}$. For the co-precipitated samples, an additional peak deconvolution procedure available in TRIOS was applied to separate partially overlapping thermal contributions. The resulting peak positions and integrated areas were used only as a qualitative indication of the complexity of the oxidation process.



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 9 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

3. RESULTS

Figure 1 shows the pulverization observed for the undoped UO_2 dry-route pellet after oxidation up to 700 °C in air. This observation is consistent with the expected complete formation of U_3O_8 during oxidation under such conditions.

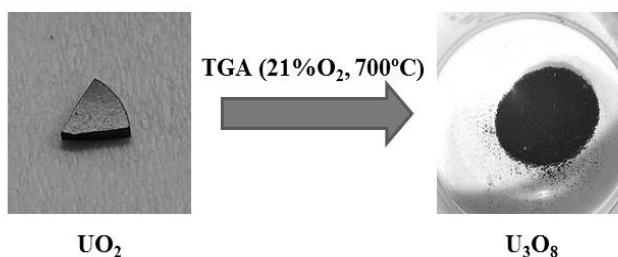


Figure 1. Visual pulverization of the undoped UO_2 pellet (obtained by dry route) after being oxidized up to 700 °C at 21% O_2 .

3.1.TGA CURVES

TGA was used to evaluate the oxidation behavior of undoped and Cr-doped UO_2 pellets by monitoring the mass gain associated with oxygen uptake during heating in air (21% O_2). The resulting curves (Figure 2.A and 2.B) provide information on oxidation onset, oxidation kinetics and the final degree of oxidation reached after heating to 700 °C.



 DIVISI3N DE FISI3N NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 10 DE 17
	REF. EXTERNA	REVISI3N 0 FECHA 23/07/2026

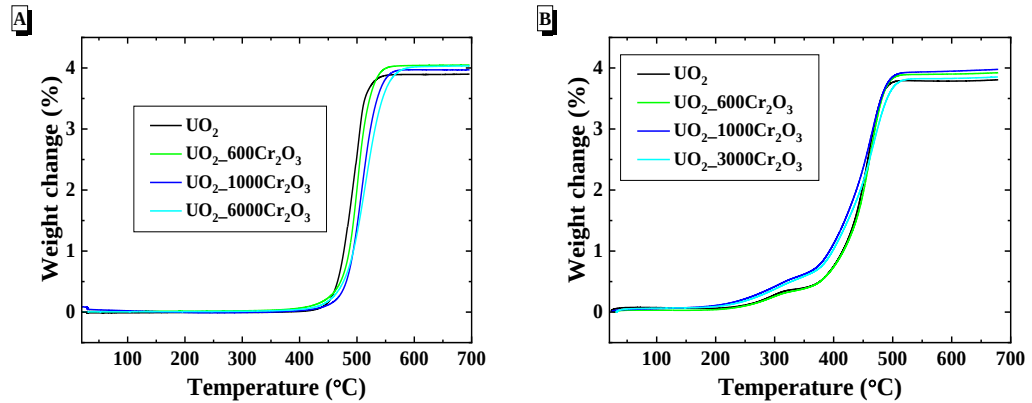


Figure 2 Oxidation curves of the ATFs studied from RT to 700 °C in air (21% O₂). A) Undoped and Cr-doped UO₂ obtained by dry route; B) undoped and Cr-doped UO₂ obtained by co-precipitation route.

All samples exhibit a progressive mass increase due to oxygen incorporation into the UO₂ lattice. However, differences are observed in the temperature range where oxidation takes place and in the shape of the oxidation curves, revealing an influence of the fabrication route. A closer examination of the oxidation temperatures and oxidation rates was performed by obtaining the first derivative of the curves and calculating the corresponding O/M values, presented in the following section.

3.2.O/M CURVES

The O/M ratio was calculated from the measured mass gain during oxidation assuming conservation of uranium and chromium atoms and complete oxygen incorporation into the oxide lattice. The increase in oxygen content was obtained from the relative mass variation according to:

$$\frac{O}{M} = 2 + \frac{m}{m_0} \cdot \frac{M_{\text{sample}}}{M_O}$$

where m/m_0 corresponds to the relative mass increase measured during oxidation, M_{sample} is the molar mass of the initial composition $U_{1-x}Cr_xO_2$ (see Table I) and M_O is the molar mass of oxygen. The final O/M values are all within a narrow interval (~2.64-2.68), as reflected in Table II, suggesting that all samples reach very similar oxidation states after heating to 700 °C. This indicates that most samples are at the U₃O₈ composition and that Cr



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 11 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

content does not modify the final oxidation degree. The oxidation mechanism appears dominated by microstructure rather than by Cr chemistry. This is reasonable because Cr concentrations of hundreds or a few thousand ppm are very small compared with the U proportion. However, the oxidation path differs between routes.

The increase in O/M observed in the dry-route samples (Figure 3.A) is sharper, indicating faster oxygen uptake once oxidation begins. This behavior is consistent with higher maximum oxidation rates and a single dominant oxidation event, related to more heterogeneous microstructures (Table II). Therefore, the oxidation front appears to propagate fast after the start.

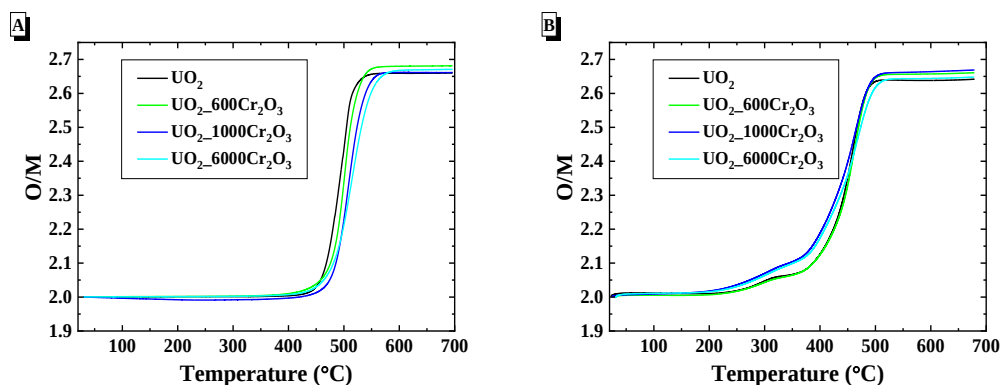


Figure 3 O/M curves of the ATFs studied from RT to 700 °C in air (21% O_2). A) Undoped and Cr-doped UO_2 obtained by dry route; B) undoped and Cr-doped UO_2 obtained by co-precipitation route.

The O/M increase in the co-precipitated samples (Figure 3.B) is more gradual and occurs through two distinguishable stages: one would be the initial oxygen incorporation into UO_2 , and next the subsequent conversion towards higher oxides ($\text{U}_4\text{O}_9/\text{U}_3\text{O}_7$ and U_3O_8). The shift of T_{max1} (Table II) from ~ 302 °C (undoped) to $\sim 326\text{-}334$ °C (1000 and 3000 ppm Cr_2O_3) indicates that chromium significantly delays this first oxidation step. The second oxidation step remains nearly unaffected by the presence of Cr (variations within the error margin).



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 12 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

Table II Calculated values from TGA curves showed in Figure 2 and Figure 3. The uncertainty associated with transition temperatures obtained from derivative analyses is estimated to be ± 2.5 °C, while the uncertainty in O/M calculations is within the experimental precision of the thermobalance.

Composition	ppm Cr ₂ O ₃	Dry Route						
		O/M f	T _{max} (inflection point) / °C		Max rate / mg/min	T ONSET / °C		
UO ₂	0	2.66	504.57		0.8873	467.99		
U _{0.9998} Cr _{0.0002} O ₂	600	2.68	501.407		0.7419	428.27		
U _{0.9996} Cr _{0.0004} O ₂	1000	2.66	508.11		0.44478	479.75		
U _{0.9979} Cr _{0.0021} O ₂	6000	2.68	515.33		0.10343	479.06		
		Wet route						
		O/M f	T _{max1} (inflection point 1) / °C	T _{max2} (inflection point 2) / °C	Max rate / mg/min	T ONSET 1 / °C	T ONSET 2 / °C	
UO ₂	0	2.64	301.68	448.18	0.06066	254.18	422.51	
U _{0.9998} Cr _{0.0002} O ₂	600	2.66	302.1	451.07	0.12132	243.85	430.41	
U _{0.9996} Cr _{0.0004} O ₂	1000	2.67	326.04	453.6	0.06066	274.84	425.81	
U _{0.9989} Cr _{0.0011} O ₂	3000	2.65	333.91	452.12	0.06066	274.92	437.96	

As mentioned, oxidation with dry-route samples occurs essentially through a single main event (Figure 2A). T_{max} values also seem to be slightly affected by the Cr content, since a $\sim 10^\circ\text{C}$ delay is detected for the sample with the highest content (6000 ppm Cr₂O₃) compared with the lowest content samples (0 and 600 ppm Cr₂O₃) (Table II), suggesting that Cr mainly affects reaction kinetics rather than the oxidation mechanism. The maximum oxidation rate decreases with increasing Cr content, nearly 50% for the 1000 ppm sample, indicating slower oxidation kinetics and enhanced oxidation resistance. This is in good agreement with the fact that dry route usually leads to less homogeneous Cr distribution with local chromia-rich areas, higher heterogeneity between grains and possible residual porosity. In addition, the higher onset temperatures observed for the samples with 1000 and 6000 ppm Cr₂O₃ also indicate greater oxidation resistance.

On the contrary, oxidation of wet-route samples starts much earlier (Table II) and involves at least two main events. Onset temperatures of the first step are around 244-275°C. The co-precipitated samples containing 1000 and 3000 ppm Cr₂O₃ exhibited the highest onset temperatures (~ 275 °C), suggesting a delay in oxidation initiation compared with undoped UO₂. Derivative analysis (not shown) reveals two oxidation stages instead of a single dominant event, the first with T_{max1} shifts from 302 °C to 334 °C as Cr content increases; and the second with T_{max2} that remains nearly constant at 448-454°C. These results indicate a more complex oxidation mechanism, probably associated with the more homogeneous microstructure produced by co-precipitation. This route usually gives atomic-



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 13 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

scale mixing of U and Cr with more homogeneous dopant distribution, more uniform grain growth and fewer compositional gradients. In this case, the best oxidation resistance is observed for the samples with 1000 and 3000 ppm Cr_2O_3 , which exhibit the highest onset temperatures and the highest T_{max1} values.

Consequently, observed oxidation resistance differences are most likely microstructural rather than compositional.

3.3.DSC CURVES

In order to clarify the oxidation sequence of co-precipitation samples, DSC curves were acquired at 21% O_2 and up to 550 °C (Figure 4). DSC results suggest the presence of more than one thermal contribution during oxidation, consistent with a multistep oxidation process.

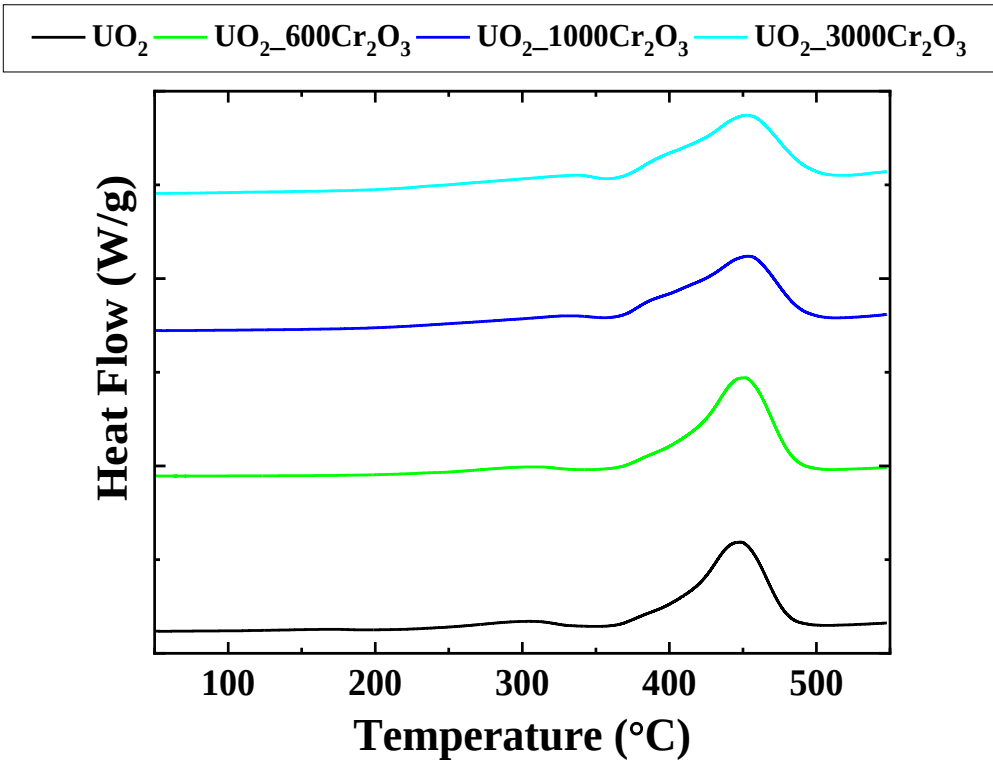


Figure 4 DSC curves of the ATFs studied from RT to 550 °C in air (21% O_2) for undoped and Cr-doped UO_2 obtained by co-precipitation route.



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 14 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

Table III gathers all the values calculated from the DSC curves in Figure 4. The first exothermic contribution (ΔH_1) decreases strongly from the undoped material to the 1000 ppm sample and then increases again for 3000 ppm. This trend agrees with the TGA results, where the 1000 ppm sample showed the greatest delay of the first oxidation stage (higher onset and higher $T_{\max 1}$). Therefore, the reduction of ΔH_1 together with the shift of $T_{\max 1}$ towards higher temperatures suggests that Cr additions, particularly at 1000 ppm, inhibit or delay the initial oxidation step. This behavior is consistent with improved oxidation resistance during the early stages of oxygen incorporation.

Table III Calculated values from DSC curves of co-precipitated undoped and Cr-doped UO_2 during oxidation in air (21% O_2) shown in Figure 4. Uncertainty for each parameter lies around 1%, taking into account the precision of the instrument.

Composition	ppm Cr_2O_3	ΔH_1 / J/g	ΔH_2 / J/g	$T_{2,1, \max}$ / °C	$\Delta H_{2,1}$ / J/g	$T_{2,2, \max}$ / °C	$\Delta H_{2,2}$ / J/g
UO_2	0	24.282	293.19	391.55	23.201	447.3	316.06
$\text{U}_{0.9998}\text{Cr}_{0.0002}\text{O}_2$	600	15.68	330.92	390.95	20.421	452.65	363.92
$\text{U}_{0.9996}\text{Cr}_{0.0004}\text{O}_2$	1000	11.754	265.34	390.89	12.79	455.33	241.22
$\text{U}_{0.9989}\text{Cr}_{0.0011}\text{O}_2$	3000	24.542	274.38	394.06	17.947	452.29	274.7

DSC measurements reveal a broad asymmetric exothermic feature in the second exothermic contribution (ΔH_2), which is consistent with a two-step oxidation process. Nevertheless, the associated enthalpy values obtained from the peak integration do not show a systematic trend with chromium concentration. Therefore, although the DSC results support the existence of different oxidation stages, a detailed interpretation of the heat released during each individual step would require further analysis and should be considered preliminary in the present work.



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 15 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

4. SUMMARY OF RESULTS

A set of Cr-doped UO_2 pellets obtained by two different methods (dry route and wet co-precipitation) were oxidized in air, and the results compared as a function of the fabrication route.

For the dry-route samples, the derivative curves exhibited a single oxidation step with only slight kinetic variations as a function of Cr concentration. In contrast, the co-precipitated samples showed two distinguishable peaks, consistent with a two-step oxidation process. The clearest influence of Cr addition is observed in the co-precipitated materials, where the first oxidation stage is shifted towards higher temperatures, *i.e.*, a delay effect is detected. Anyhow, comparison of the outcomes obtained for the two sets of samples indicates that the fabrication route exerts a stronger influence on oxidation behavior than chromium concentration itself, suggesting that oxidation resistance is primarily controlled by microstructural characteristics such as grain structure, pore distribution and dopant homogeneity rather than by the final chemical composition.

Therefore, it is shown that fabrication route affects oxidation kinetics. Additional characterization would be needed to isolate the separate roles of porosity, grain size, and Cr distribution, using for example XRD or Raman spectroscopy techniques to obtain the phase sequence after oxidation.



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 16 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

5. ACKNOWLEDGMENTS

This research is part of the project of R+D+i PID2021-124913OA-I00, IONMAT project funded by MICIU/AEI/10.13039/501100011033/, Proyectos de Generación de Conocimiento 2021.



 DIVISIÓN DE FISIÓN NUCLEAR	INFORME DFN/RA-09/SP-26	HOJA 17 DE 17
	REF. EXTERNA	REVISIÓN 0 FECHA 23/07/2026

6. REFERENCES

- [1] A. Milena-Pérez, L. J. Bonales, N. Rodríguez-Villagra, S. Fernández, V. G. Baonza, and J. Cobos, "Raman spectroscopy coupled to principal component analysis for studying UO₂ nuclear fuels with different grain sizes due to the chromia addition," *Journal of Nuclear Materials*, vol. 543, p. 152581, 2021.
- [2] A. M.-P. N. Rodríguez-Villagra, S. Fernández-Carretero, L.J. Bonales, L. Gutiérrez, A., Núñez, L. Serrano, S. Durán, L. Anta, J. Cobos, H. Galán, "Production and characterization of Cr-doped UO₂ as an atf surrogate by dry powder method (ionmat project. Subtask 2.1)," CIEMAT, 2024.
- [3] A. Milena-Pérez, "Production and characterization of Cr-doped UO₂ as an atf surrogate by coprecipitation route (ionmat project. Subtask 2.2)," CIEMAT, 2026.
- [4] J. Novak, I. J. Hastings, E. Mizzan, and R. J. Chenier, "Post irradiation behavior of UO₂ fuel I: elements at 220 to 250°C in air," *Nuclear Technology*, vol. 63, pp. 254-265, 1983.
- [5] J. M. Elorrieta, L. J. Bonales, N. Rodríguez-Villagra, V. G. Baonza, and J. Cobos, "Spent fuel matrix oxidation studies under dry storage conditions," *MRS Advances*, vol. 2, pp. 675-680, 2017.
- [6] F. Valdivieso, V. Francon, F. Byasson, M. Pijolat, A. Feugier, and V. Peres, "Oxidation behaviour of unirradiated sintered UO₂ pellets and powder at different oxygen partial pressures, above 350°C," *Journal of Nuclear Materials*, vol. 354, pp. 85-93, 2006.
- [7] K. K. Bae, B. G. Kim, Y. W. Lee, M. S. Yang, and H. S. Park, "Oxidation behavior of unirradiated UO₂ pellets," *Journal of Nuclear Materials*, vol. 209, pp. 274-279, 1994.
- [8] R. J. McEachern and P. Taylor, "A review of the oxidation of uranium dioxide at temperatures below 400°C," *Journal of Nuclear Materials*, vol. 254, pp. 87-121, 1998.
- [9] P. Taylor, D. D. Wood, and A. M. Duclos, "The early stages of U₃O₈ formation on unirradiated CANDU UO₂ fuel oxidized in air at 200–300°C," *Journal of Nuclear Materials*, vol. 189, pp. 116-123, 1992.



<u>FIRMANTE</u>	<u>NOMBRE</u>	<u>FECHA</u>	<u>NOTAS</u>
FIRMANTE[1]	ABEL MILENA PEREZ	23/09/2026 10:29 Sin acción específica	
FIRMANTE[2]	MARIA NIEVES RODRIGUEZ VILLAGRA	23/09/2026 10:36 Sin acción específica	
FIRMANTE[3]	M.SOLEDADE FERNANDEZ FERNANDEZ	23/09/2026 11:01 Sin acción específica	
FIRMANTE[4]	ENRIQUE MIGUEL GONZALEZ ROMERO	23/09/2026 13:35 Sin acción específica	

