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FEASIBILITY STUDY FOR REMOVAL OF SiC COATING
IN HTGR-TYPE FUEL BY F₂-FLUORINATION

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Mitsuru MAEDA and Eiji YAGI*

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Feasibility Study for Removal of
SiC Coating in HTGR-type Fuel by F₂-Fluorination[#]

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A decladding process only by the gasification reaction, is proposed for the TRISO-type particle fuel through fluorination experiments of SiC and PyC. The process may be adapted to the aqueous separation processes such as Thorex or Purex by framing a "Burn-Fluorination-Reburn-Leach" flowsheet. Feasibility of the proposed flowsheet was confirmed by a boat experiment with unirradiated coated particle. By both experiment and calculation, optimization of the fluorination step is shown to be the key problem for minimum kernel loss.

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A summary of the oral representation at the 8th International Symposium on Fluorine Chemistry held at Kyoto in August, 1976 (I-24)

F₂フッ素化による高温ガス炉用燃料炭化硅素脱被覆の予備検討[#]

日本原子力研究所東海研究所燃料工学部

前田 充・八木 英二^{*}

(1977年4月4日受理)

炭化硅素および熱分解炭素のフッ素化実験により、ガス化反応だけによるTRISO型被覆粒子燃料脱被覆法を提案した。この脱被覆法は、“Burn - Fluorination - Reburn - Leach”から成るフローシートを描くことにより、Thorex, Purex法など湿式再処理法にも適用することが出来る。この脱被覆法の原理的可能性を未照射被覆粒子を用いたボート実験により確認した。またこの実験結果および計算による評価から、燃料ロスを最小とするためのフッ素化工程の最適化が最も重要であることを指摘した。

* 現在、三菱金属（株）

本報告は、第八回国際フッ素化学シンポジウム（1976年8月、京都）における口頭発表（I-24）を基にまとめたものである。

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1 Introduction

In the reprocessing of HTGR-type fuel, it is necessary to introduce a complex head-end process for the effective kernel dissolution. The principal processing steps are; (1) disassembling, (2) removal of matrix graphite, (3) decoating of particle fuel, (4) removal of volatile fission products and (5) acid leaching.

In the processes being developed in the United States¹⁾ and West Germany²⁾, the graphite matrix and outer pyrolytic carbon (PyC) coating is removed by "Crush and Fluid-bed Burning," leaving the unburned silicon carbide (SiC) coating. Then, this coating is planned to be crushed by physical methods such as roll-grinding or pneumatic jet-grinding, because of the high chemical stability of SiC coating. These methods, however, have such technical problems as grinder maintenance and radioactive powder handling under high radiation. Therefore, removal of SiC by any gasification reaction will provide a simpler process, eliminating the above technical problems.

Two systems using HF ³⁾ and Cl_2 ⁴⁾ are proposed for the gasification reaction, although their potentialities seem to be limited due to their high corrosiveness and their intense reaction conditions.

The present study was conducted to find another potential reaction without the above limitations and to show its chemical feasibility. Possible gas reaction systems have been reviewed and evaluated through a literature survey and thermodynamic calculations⁵⁾.

The fluorination reaction of SiC with elemental fluorine is, there, chosen. In this reaction, however, kinetic and even initiation conditions for fluorination are not known sufficiently to show its chemical feasibility, only except the little informations^{6,7)}.

2 Experimentals,

SiC powder of -50 + 100 mesh size was prepared by grinding a nuclear grade β -SiC plate and sieving their ground powders. In order to remove free carbon, silica and other impurities, the powder was purified through oxidation, linsing with HF and NaOH-solution and finally washing with water. The coated particles used were TRISO-types with and without outer isotropic PyC coating prepared by Nukem GmbH and Japan Nuclear Fuel Ind. Ltd. (Nihon Genshinryo Kogyo), respectively. Fluorine from Air Products Co. was used after passing through a NaF trap to remove HF and diluting with dehumidified oxygen or nitrogen.

Fluorination rates of SiC and PyC were measured gravimetrically with a thermobalance, using 50 ~ 500 mg samples on a pan suspended in a monel reactor ($46^\phi \times 130^l$).

Process feasibility experiments on the proposing flow-sheet were carried out using about 1 g of TRISO particle on the alumina boat placed horizontally in a nickel reactor ($40^\phi \times 500^l$). A small trap loaded with NaF pellets (Harshaw Chem. Co.) was placed behind the above reactor, in order to collect the volatilized UF_6 in the SiC fluorination step.

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The uranium content in samples was determined by dissolution in boiling 13 N HNO₃ added H₂SO₄, and by Arsenazo III colorimetry. The percentage of broken particles was also measured by applying the same leaching and analytical method.

3 Fundamental feasibility study

3.1 Fluorination of SiC powder

Fig. 1 shows fluorination profiles of β -SiC powder, correlating the unreacted fraction with the unreacted core model⁸⁾. Most of the curves are bent dividing the reaction scheme into two phases, i.e. 1st and 2nd. The latter reaction is known to prevail under mild conditions.

The slope in this plot gives the apparent reaction rate constant k' :

$$k' = \frac{k}{r_o \cdot \rho} \text{-----} (1)$$

where, k : reaction rate per unit surface area

r_o : initial radius of the powder

ρ : density of the powder

The observed k' 's for two dilution gases of oxygen and nitrogen are plotted on the Arrhenius plane as in Fig. 2. The shaded area shows k' 's in the 1st phase reaction. The activation energy in the 2nd phase is almost the same, 15 kcal/mol in the both diluent gases, while k' 's for the 1st phase are throughly independent of the temperature.

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Fig. 3. The reaction orders found are 1.0 and 0.5 for the 1st and the 2nd phase reaction, respectively when oxygen is used as the diluent.

As seen above, the 2nd phase reaction, which is the main, is chemically controlled. The 1st phase reaction which is possibly diffusion-controlled may be caused by peculiar reasons such as local heating due to existence of the highly reactive fine powder.

Remarkable differences in reactivity is exhibited between oxygen and nitrogen as the diluent, although the cause is not known yet.

3.2 Decladding of SiC coating of the particle by fluorination

Decladding profiles of the SiC coating are shown in Fig. 4. Linear decrease of the particle weight ceases at time τ indicating that the fluorination zone has reached to the inner PyC surface. From the observed τ , the time for ceasing of the weight decrease, an averaged decladding rate R is defined as,

$$R = \frac{\ell_0}{\tau} \text{-----} (2)$$

where ℓ_0 : average thickness of SiC coat

Fig. 5 compares the above R 's with calculated values which were obtained from eq. (1) using k 's in the 2nd phase reaction. From the good agreement in the system of oxygen dilution, the unreacted core model will be actually applied to the coated particle and k ' in the 2nd phase reaction will

give the most probable decladding rate.

The decladding rate R of SiC coating is summerized in Table 1.

3.3 Fluorination of pyrolytic carbon

The above results will be enough to show the possibility of a fluorinative decladding of SiC coating, especially under rather mild conditions. In order to give more practical process frame, however, the reactivity of PyC with elemental fluorine should be clarified.

Fig. 6 shows the apparent fluorination rate of the PyC compared with the SiC and a natural graphite⁹⁾. Marked unreactivity of the PyC is found below 400°C and with low concentrated fluorine.

This result suggests a feasibility of the selective removal of SiC coating without kernel volatilization and unnecessary fluorine consumptions.

4 Proposed flowsheet and the preliminary feasibility study

4.1 Proposed flowsheet

Combining the unreactive properties of SiC against oxygen, it will be possible to frame a simple head-end process as shown in Fig. 7, consisting of "Burn-Fluorination-Reburn-Leach or-Fluorination" which removes matrix graphite /outer PyC coating, SiC coating and inner PyC coating, stepwise and selectively¹⁰⁾.

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As only gas reaction constitutes the process step,

some simple and continuously operated flowsheets would be expected with less radioactive powder handling and without machine maintenance. The selectivity of fluorination in the SiC decladding step will enable the process to be adapted to the aqueous Thorex or Purex process as well as to the non-aqueous process such as the fluoride volatility process.

4.2 Preliminary feasibility study on the flowsheet

A preliminary study was conducted in a boat-scale experiment in order to prove feasibility of the process principle with a view of its adapting to the aqueous separation process.

Principal experimental conditions are summarized in Table 1. Simulation of the broken particle is necessary in order to know the effect on the kernel loss. As the particle used, however, had been known to be broken to some extent (about 4% of charged) even in the primary burning step, simulated broken particles were not added.

Uranium balances are presented in Table 2. The feasibility of the proposed process is proved through relatively good kernel recoveries in Run-01 and-03 giving 96 ~ 98%.

The high unrecovered fraction in Run-02 seems to be primarily due to uncomplete burning of the outer PyC coating, which caused secondly the ineffective decladding of SiC in the succeeding fluorination step. The result suggests that the complete decladding is necessary for the primary burning as well as for the fluorination in order to obtain high recovery of kernel.

Other more significant problem is volatilization of the kernel as UF_6 . Although losses in this study are not so high, their ratios to the broken particle give values as high as 0.16 ~ 0.24, which suggests about one fifth of the broken particles may be lost as volatilizing UF_6 . Considering the high particle breakage and the amoeba effect in irradiated fuel, volatilization of kernel in broken particles will increase the whole losses and become the key problem in this process, when it is adapted to the aqueous process.

5 Discussions on the optimization of SiC fluorination conditions

When applying the concept to the conventional aqueous process, operating conditions of the SiC fluorination step should be optimized, considering the following process criteria:

- (1) Minimum kernel loss due to the fluorination of broken particles
- (2) Limited decladding rate for controlling the particle temperature enough low to prevent the sintering,
- (3) Practical processing time competitive with the already proposed physical methods,
- (4) High fluorine utilization for chemicals cost and simple off-gas treatment

A study was made to select optimum fluorination conditions.

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Fig. 8 indicates the effect of temperature on the decladding time and the kernel loss. The decladding time was calculated for JAERI'S is Mark III type fuel¹¹⁾, using the equation on Table 1. The calculated fuel loss is the volatilized fraction of the kernel in broken particles within the above decladding time, which was obtained with the published data of UO_2 ¹²⁾.

Particles surface temperature depends on the fluorination rate and the heat removal rate. The thin solid lines in Fig. 8 show limit of the decladding rate, which is expressed by the decladding time, for keeping the given particle temperatures. This critical decladding rate was obtained by a simple assumption based on the heat balance for one particle in a fluidized-bed, which will provide more safety allowances from the view point of sintering protection than the calculation based on the heat balance of the bed influenced by the wall heat transfer.

A reference process requirement of 1% kernel loss for broken particle, 2 hr. decladding time and 700°C particle temperature gives the shaded temperature limit for 5 vol. % fluorine. Fig. 8 suggests the upper limit of the fluorination temperature is not determined by sintering but by kernel loss.

The fluorine concentration should be optimized in its utilization efficiency which is closely related to the reactor type. Considering the dependency of the decladding rate on the fluorine concentration and fluorination characteristics of the PyC, lower concentration is recommended.

Therefore, the proposed chemical decladding process is summerized in Fig. 7.

6 Conclusions

Through fluorination experiments of SiC and PyC, a decladding process only by the gasification reaction, is proposed for the TRISO-type particle fuel. The process will be adapted to the aqueous reprocessing by framing "Burn-Fluorination-Reburn-Leach" flowsheet. The feasibility of the proposed flowsheet was proved by boat-experiments with unirradiated coated particle fuel. Optimization of the fluorination step is shown to be the key factor for minimum kernel loss in the suppression of the kernel volatilization in broken particles.

In order to further clarify the feasibility, the following studies are necessary:

- (1) Engineering-scale experiments in a fluidized-bed or spouted-bed reactor,
- (2) Experiments with irradiated fuel, especially in proving the influence of the broken particle on kernel loss,
- (3) Process studies to reduce the fraction of broken particle in the "Crush and Burning" step.

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References

- 1) Notz, K. J. : "Selected studies in HTGR reprocessing development", ORNL-TM 5328 (1976)
- 2) Merz, E. and Kaiser, G. : "Stand der endvicklungsarbeiten zur HTR-wiederaufarbeitung", Reaktortagung, p 331 (1975)
- 3) Kreutz, R. et al. : "Hydrofluorination of U/Th oxide and carbides with a coating of dry reprocessing of nuclear fuels containing thorium", Kerntechnik, Vol. 13, p 21 (1971)
- 4) Bohnenstingl, J. et al. : "CHRORINEX-development of a process for high temperature chlorination of Th containing nuclear fuel elements as a head-end process in fuel reprocessing", Jul-1129-CT (1974)
- 5) Yagi, E. and Maeda, M. : "Literature survey and evaluation of the removal of silicon carbide coating by reaction with gases in HTGR fuel", JAERI-M 5840 (1974)
- 6) Cathers, G. I. : unpublished ORNL data, cited from "Head-end Process for Graphite-base Carbide Reactor Fuels", by L. M. Ferris, in "Progress in Nuclear Energy Series, Process Chemistry", Vol. 4, p 121 (1970)
- 7) Schumb, W. C. et al. : "The fluorination of carbides", J. Am. Chem. Soc., Vol. 81, p 806 (1959)
- 8) Kunii, D. and Levespiel, O. : "Fluidization Engineering", Chap. 15, p 480, John Wiley & Sons Inc. (1969)
- 9) Watanabe, S. et al. : "A reactions of graphite and fluorine", Denki-Kagaku (J. Electrochem. (Japan)), Vol.

35, p 19 (1967)

- 10) Yagi, E. and Maeda, M. : "Decladding Process for SiC Coated Particle Fuel", Japanese Pat. 822694, Jul. 28th, 1976.
- 11) Shimokawa, J. et al. : "Fundamental Conceptual Design of the Experimental Multi-purpose High-temperature Gas-cooled Reactor", JAERI-M 6141 (1975)
- 12) Iwasaki, M. et al. : "Kinetic studies of the fluorination of uranium oxides by fluorine (2), Fluorination of UO_2 ," J. Inorg. & Nucl. Chem., Vol. 26, p 1863 (1964)

Table 1 Decladding Rate of SiC Coating

Decladding rate : R for oxygen diluted

$$R = -(dl/dt) = k_0 \cdot \text{Exp}(-\Delta E/RT) \cdot (C)^n$$

when $k_0 : 1.6 \times 10^6 \mu/\text{min}$

$\Delta E : 15 \text{ kcal/mol}$

$n : 0.5$

$C : F_2 \text{ mole fraction at 1 atm.}$

Table 2 Experimental conditions for feasibility study on "Burn-Fluorination-Reburn-Leach" Process

Material : TRISO particle with UC_2 kernel, 1g
 Gas flow rate : 300 ml/min.

Conditions	Run-01	Run-02	Run-03
1ry Burning			
Temperature	780°C	880°C	780°C
Gases	Air	Air	Air
Reaction time	4.7 h	1.5 h	4.5 h
Fluorination			
Temperature	310°C	320°C	320°C
Gases	16 vol.% F_2-N_2	16 vol.% F_2-N_2	16 vol.% F_2-N_2
Reaction time	2.0 h	4.3 h	5.0 h
2ry Burning			
Temperature	880°C	880°C	880°C
Gases	Air	Air	Air
Reaction time	3.0 h	1.5 h	3.5 h
Leaching			
Temperature	boiling	boiling	boiling
Reagent	13 N- HNO_3	13 N- HNO_3	13 N- HNO_3
Leaching time	0.5 h	0.5 h	0.5 h

Table 3 Uranium balance in feasibility study of
"Burn-Fluorination-Reburn-Leach" process

Uranium balance ^{a)}	Run-01	Run-02	Run-03
Recovered by leaching	98.2%	75.3%	96.5%
Unleached or not decladded ^{b)}	0.7	23.8	2.8
Volatilized as UF ₆ (collected on NaF trap)	1.1	0.9	0.7

Particle breakage in dry burning	4.3%	4.4%	—
Relative volatilization to broken particle	26	20	16

a) % of total uranium accounted for

b) Accounted by releaching after grinding the
unleached residues

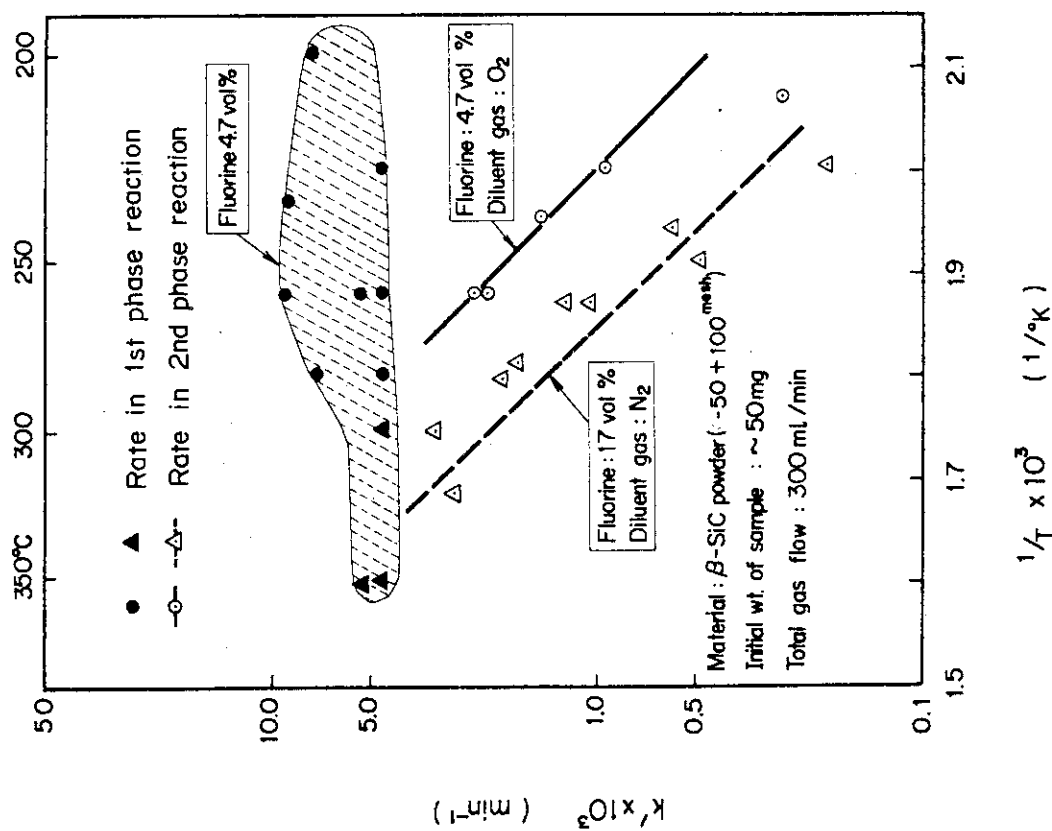


Fig. 2 Arrhenius plot of fluorination rate of SiC powder

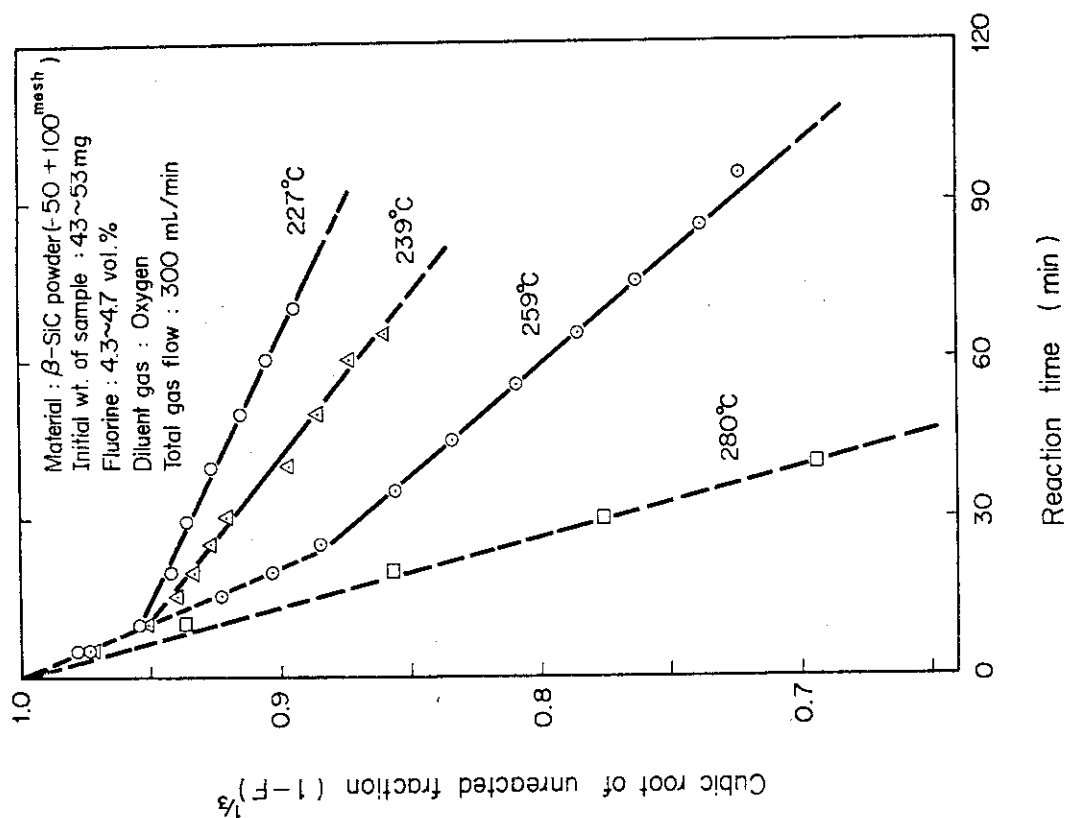


Fig. 1 Application of the unreacted core model to reactions of SiC powder with fluorine

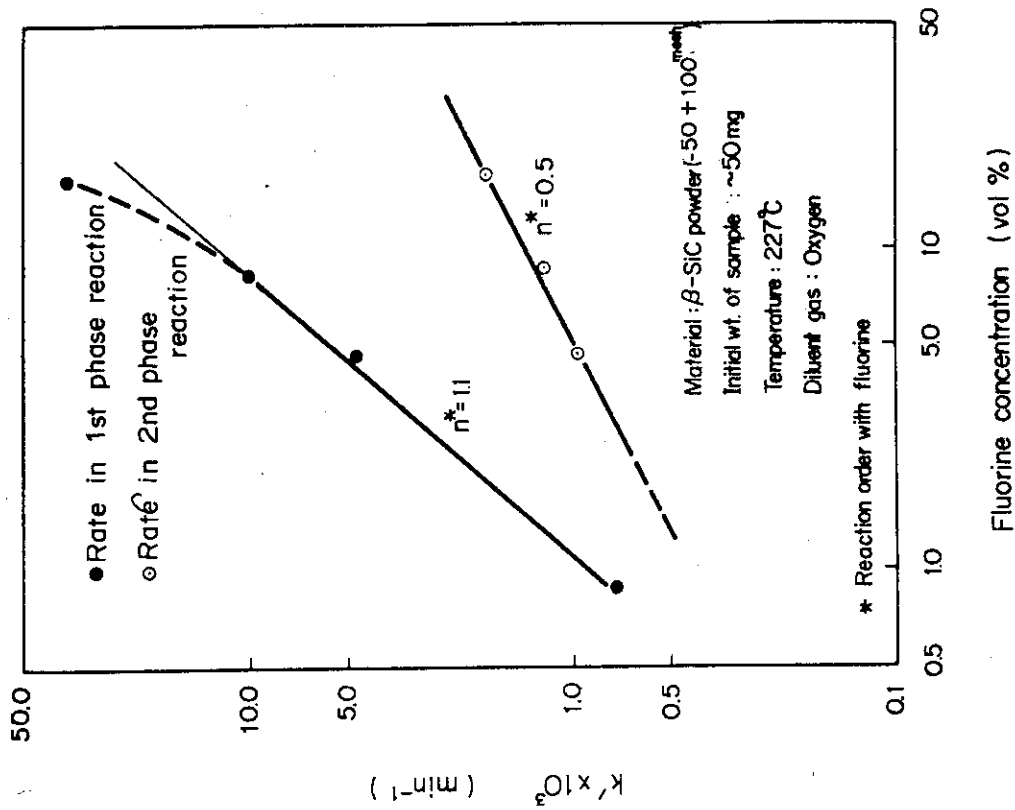


Fig. 3 Effect of fluorine concentration on fluorination rate of SiC powder

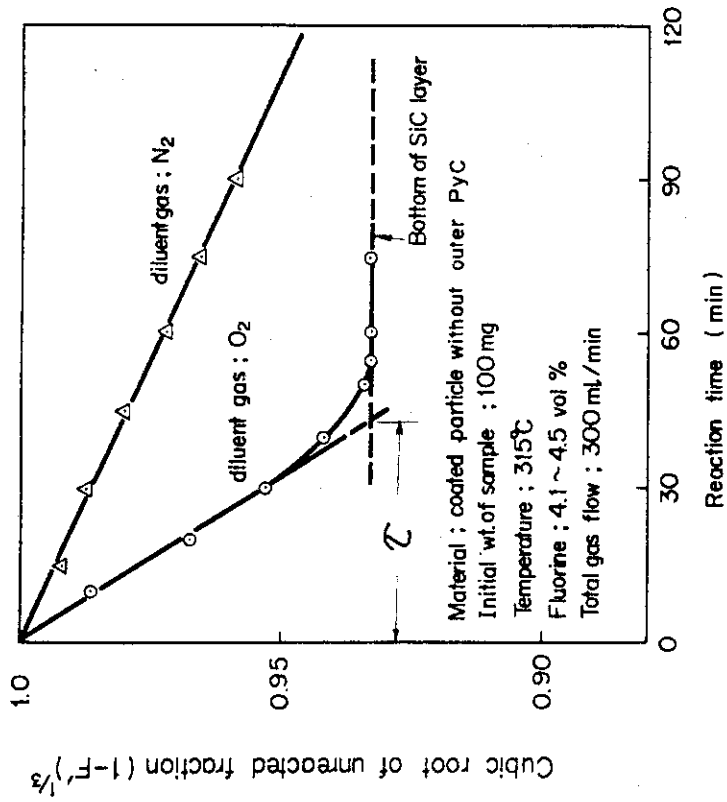


Fig. 4 Dechloriding profile of SiC coating with fluorine

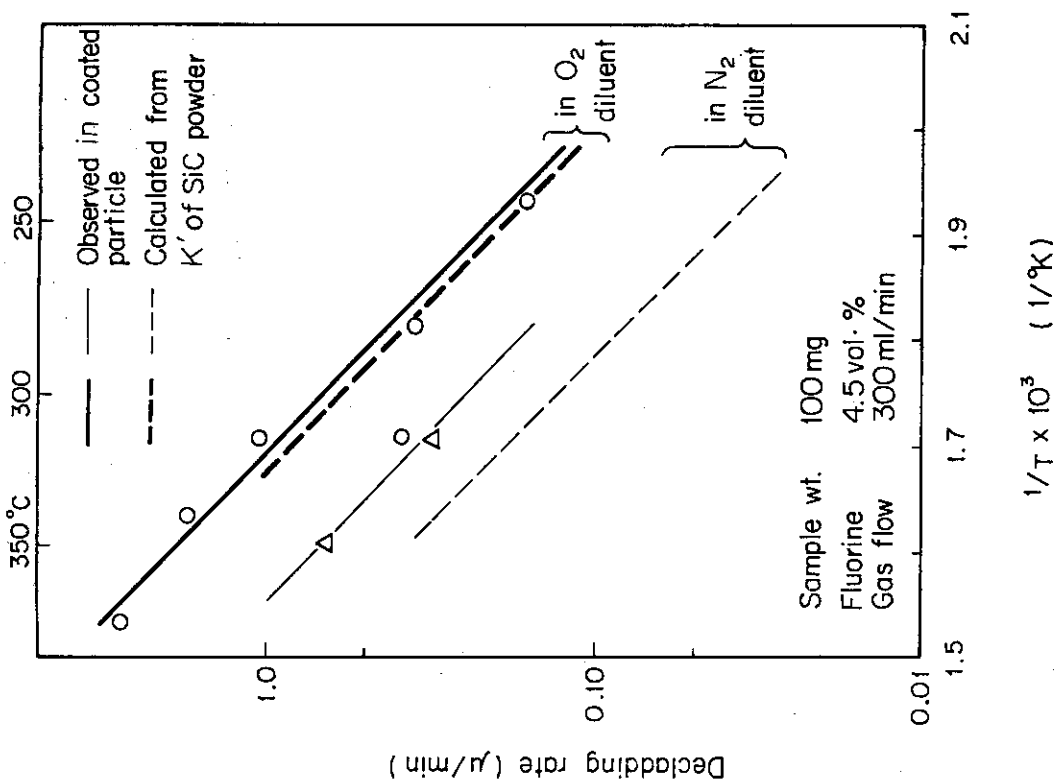


Fig. 5 Dechlorating rates of SiC on coated particle with fluorine

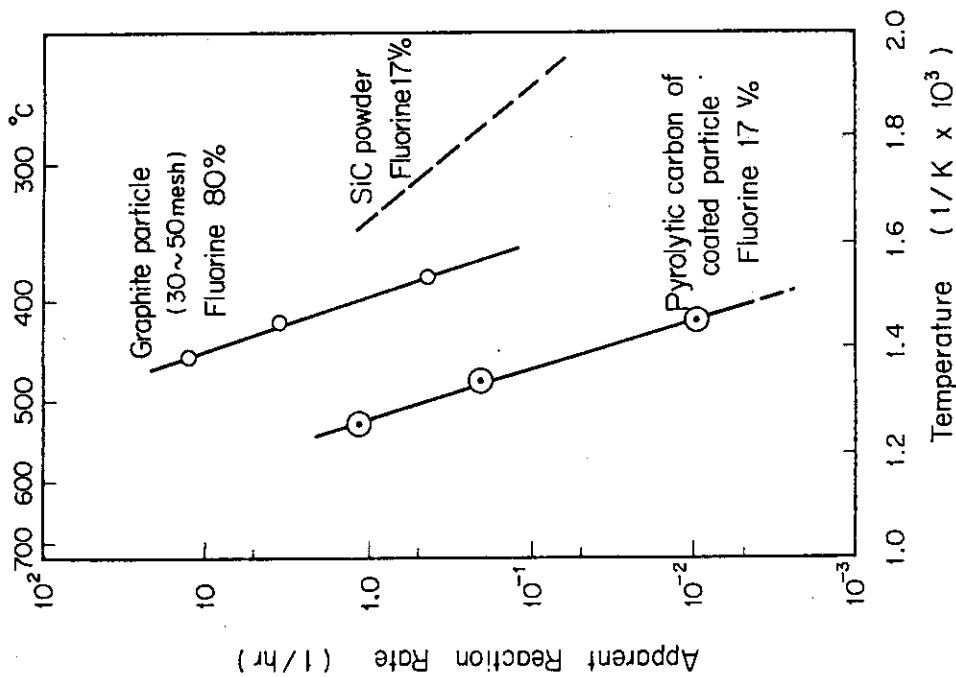


Fig. 6 Fluorination of pyrolytic carbon

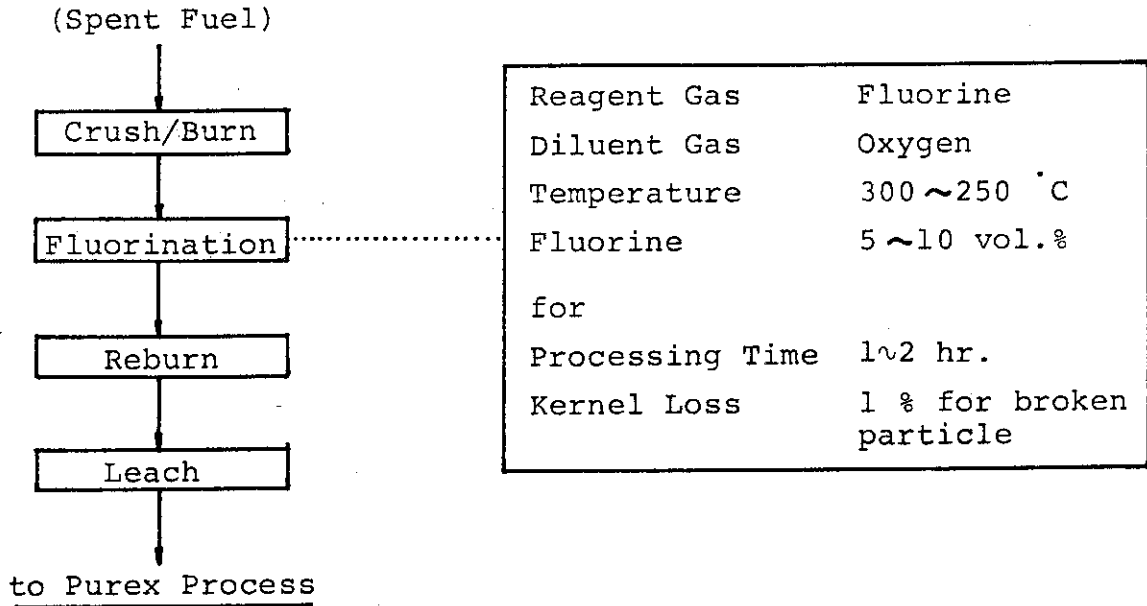


Fig. 7 Proposed chemical decladding process

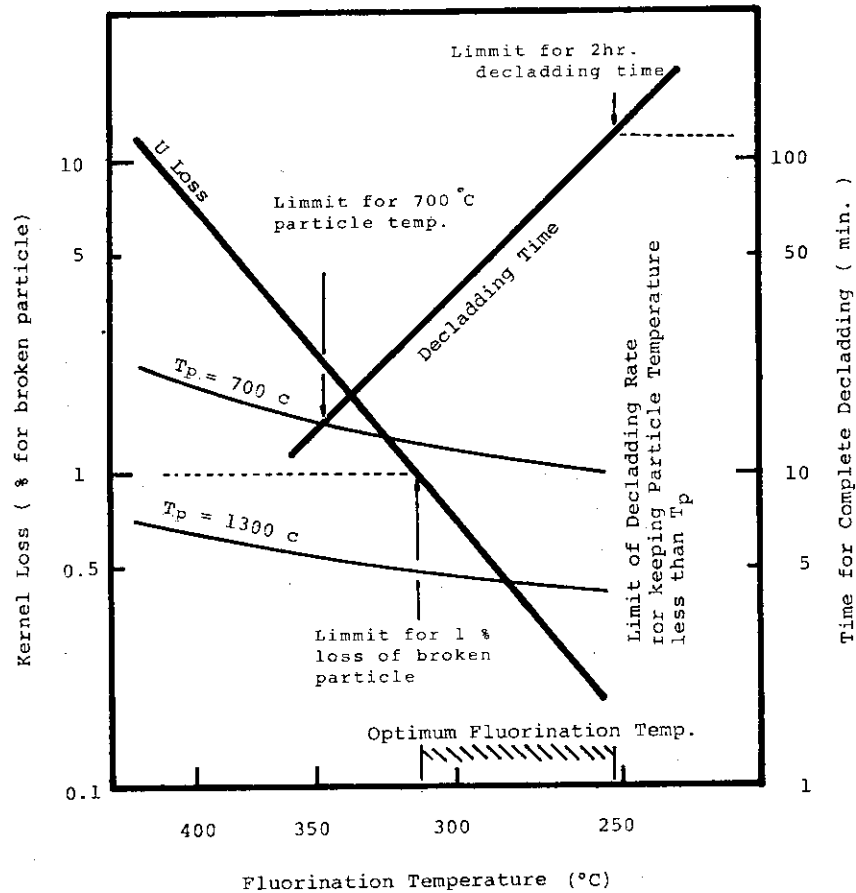


Fig. 8 Optimization of fluorination condition in SiC decladding step