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Synthesis and Recommendations

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Synthesis and Recommendations

Abstract

Tribology and corrosion phenomena are key issues in the selection of materials and the design, operation and lifetime of components and systems in helium atmosphere. Therefore a program has been proposed to study these phenomena for the different situations to be considered in the reactor. It has been focused on VHTR conditions not covered by the FP5 program, in particular higher temperatures and conditions of graphite/metal and graphite/graphite contacts more representative of a realistic environment.

New grades of graphite have been tested on two tribological devices in CEA Cadarache and in ANP-F Le Creusot (technical center): PCEA (from Graftech UCAR) and NBG-17 (from SGL Carbon GmbH), in like-on-like or graphite / metal type of contact. The other parameters are the load and the temperature. The tests are realized in helium + impurities.

Mild wear has been observed in all cases. The coefficient of friction depends on the atmosphere content, and particularly oxygen level. PCEA seems to have a better behavior in regards of wear and friction.

This document gives some recommendations aiming at minimizing the graphite debris in the reactor.

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SUMMARY / CONCLUSIONS

Tribology and corrosion phenomena are key issues in the selection of materials and the design, operation and lifetime of components and systems in helium atmosphere. Therefore a program has been proposed to study these phenomena for the different situations to be considered in the system. It has been focused on VHTR conditions, which were not covered by FP5 program, in particular concerning higher temperature, the graphite/metal and graphite/graphite contacts that have been investigated and tested in closer representative conditions.

New grades of graphite have been tested on two tribological devices in CEA Cadarache and in ANP-F Le Creusot (technical center): PCEA (from Graftech UCAR) and NBG-17 (from SGL Carbon GmbH), in like-on-like or graphite / metal type of contact. The other parameters are the load and the temperature. The tests are realized in helium + impurities.

Mild wear has been observed in all cases. The coefficient of friction depends on the atmosphere content, and particularly oxygen level. PCEA seems to have a better behavior in regards of wear and friction.

KEY WORDS

RAPHAEL – Tribology – Corrosion – Helium + impuruties – Tests – CEA – ANP-F – Friction coefficient – Wear – Graphite – 800H

ABBREVIATIONS

Cf	Coefficient of friction
VHTR	Very High Temperature Reactor

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[1] NFTM R05.1038 Ind 2 - RAPHAEL / SP-CT (Component DevelopmenT) - WP3: TRIBOLOGY AND CORROSION - WORK PLAN

[2] RAPHAEL-0608-D-CT3-1 – Review of tribology and corrosion conditions of components for HTR and VHTR

[3] RAPHAEL-0610-D-CT3-2 – Past experience from gas cooled reactor useful for VHTR

[4] RAPHAEL-07/03-D-CT3-3 – Test program definition

[5] RAPHAEL-09/07-D-CT3-4 – Realization and evaluation of test programme

1. INTRODUCTION

Tribology and corrosion phenomena are key issues in the selection of materials and the design, operation and lifetime of components and systems in helium atmosphere. Therefore a program has been proposed to study these phenomena for the different situations to be considered in the system. It has been focused on VHTR conditions, which were not covered by FP5 program, in particular concerning higher temperature, the graphite/metal and graphite/graphite contacts that have been investigated and tested in closer representative conditions.

The various stages of this study were:

- Review of tribology and corrosion conditions of components for HTR and VHTR;
- Past experience from gas cooled reactor useful for VHTR;
- Test program definition;
- Realization and evaluation of test program;
- Synthesis and recommendations.

The partners were ANP-F (1); CEA (6); ANP-D (11); FZJ (12) and NNC (18).

This work package had connections with other sub-projects: SP-ML (materials development), SP-SI (system integration), SP-ST (safety) and GCFR (Gas Cooled Fast Reactor);

Technical meetings have been held regularly during the project.

Meeting N°	**Date**	**Location**	**Object**
1	31st May 2005	NNC, Manchester	Work plan edition
2	20th October 2005	AREVA tower – Paris	Second progress meeting
3	April, 21st 2006	AREVA NP – Lyon	Intermediate progress meeting
4	May, 31st to June, 2nd 2006	NNC, Manchester	Third progress meeting
5	November, 13th & 14th 2006	AREVA tower – Paris	Fourth progress meeting
6	February, 1st 2007	AREVA NP – Lyon	Intermediate progress meeting
7	June 13th & 14th 2007	NNC, Knutsford, UK	Fifth progress meeting
8	October 16th & 17th 2007	Tractebel, Brussels, Belgium	Sixth Progress meeting
9	May 20th & 21th 2008	ENEA, Bologna, Italy	Seventh Progress meeting
10	November 17th 2008	CEA, Cadarache, France	Eighth Progress meeting
11	May 5th, 2009	AREVA, Paris La Défense, France	Ninth Progress meeting

2. SYNTHESIS OF TRIBOLOGICAL TESTS

Tests have been performed on two test benches located in CEA Cadarache and in ANP-F technical center in Le Creusot (France). As a matter of interest, both test benches are described in Figure 1 and Figure 2.

- **Pins / rail friction:**
  - plane/plane contact (0,5 cm²),
  - Alternative motion,
  - load: **0 – 20 MPa**,
  - Amplitude: up to **20 mm**,
  - Frequency: up to **6 Hz.**
- **environment Parameters:**
  - Temperature : up to **1000°C**,
  - Steam, impurities.

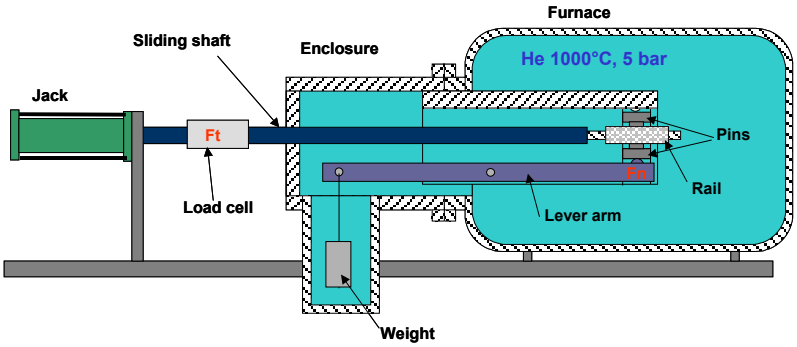
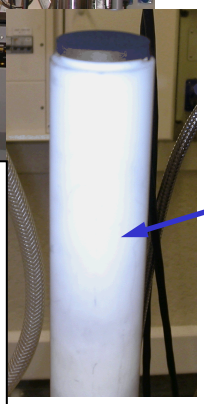
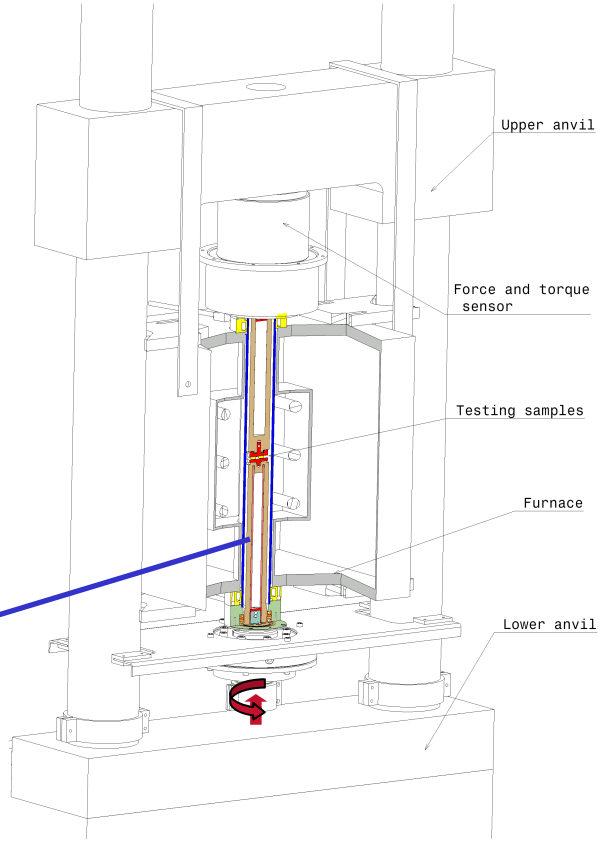


FIGURE 1:CEA TRIBOMETER



- Temperature up to 1200°C;
- Pressure: atm + ε;
- Helium + impurities;
- Alternative movement (± 9 mm) or fretting (amplitude from ±10 to ±200 µm, frequency up to 100 Hz);
- Contact pressure from 0.5 to 1000 MPa (plane on plane or pin on disk).



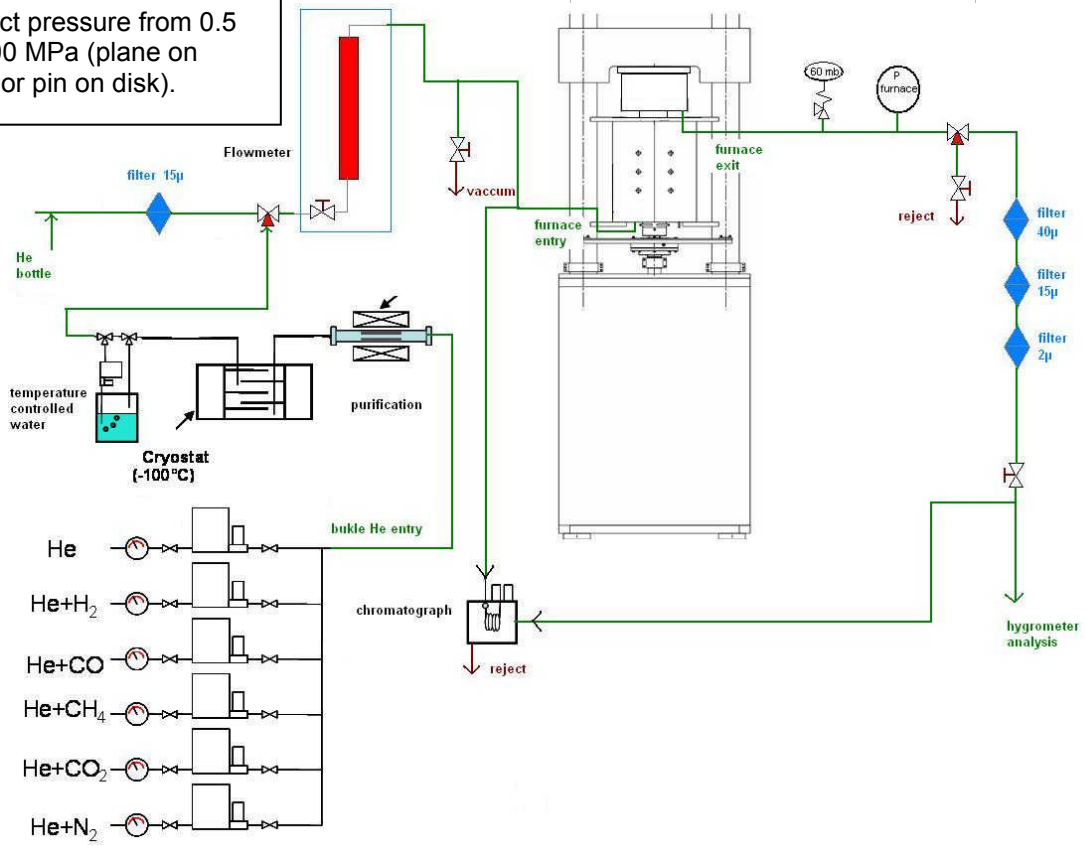


FIGURE 2: ANP-F TRIBOMETER (URANIE)

The main results obtained in task D-CT3.4 (document [5]) are summarized and compared here after in Table 1 and in Figure 3.

Environment:
Low gas pressure
New samples (non pre-oxidation)

Gas: Normal conditions He + impurities
Covered length: 200 m
Displacement velocity: 1 cm/s

N°	Component / contact	Material 1 Disk / rail	Material 2 Pin	Temper. (°C)	Load (MPa)	Tribometer ANP	Tribometer CEA	Remark	Results: Wear depth (mm) ANP	Results: Wear depth (mm) CEA	Results: Friction coefficient ANP	Results: Friction coefficient CEA
1	Core / core support	PCEA	PCEA	1000	10	X	X		<0.02	<0.02	0,47	0,22
2	Core / core support	PCEA	PCEA	1000	20	X		High load at the bottom	<0.02		0,57	
3	Core / core support	PCEA	PCEA	800	10	X			<0.02		0,88	
4	Core / core support	PCEA	PCEA	800	5		X			<0.01		0,18
5	Core / core support	NBG-17	NBG-17	1000	10	X			<0.06		0,60	
6	Core / core support	NBG-17	NBG-17	800	10	X			<0.02		0,92	
7	Core / core support	NBG-17	NBG-17	800	5		X			<0.01		0,17
8	Core barrel / internals	800H	PCEA	850	10	X	X	accidental condition	<0.01	<0.03	0,45	0,04
9	Core barrel / internals	800H	NBG-17	850	10	X			<0.01		0,81	
10	Core barrel / internals	800H	PCEA	500	10		X	Normal condition		<0.05		0,04
11	Core barrel / internals	800H	NBG-17	500	10	X			<0.01		0,69	

	Manufact	Grade	Coke	Process	Status
Graphite 1	GrafTech	PCEA	Petroleum	Extrusion	Major
Graphite 2	SGL Carbon	NBG-17	Pitch	Vibro-moulded	Minor

TABLE 1: SYNTHESIS OF TRIBOLOGICAL TEST RESULTS

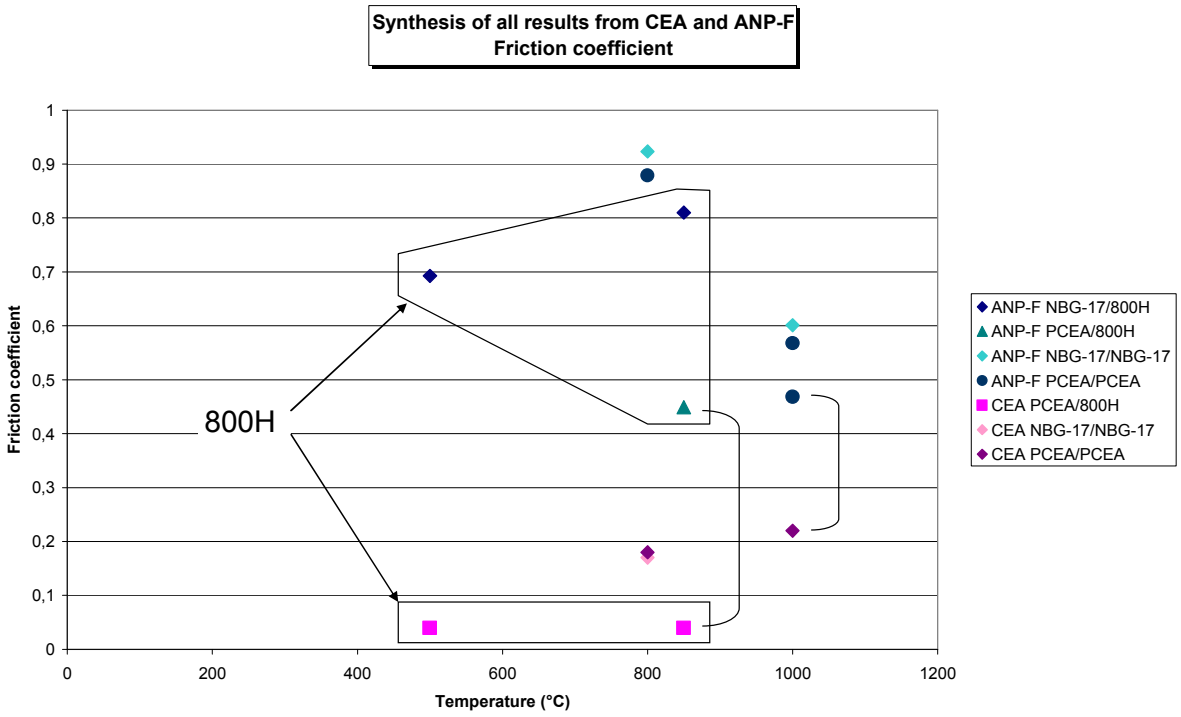


FIGURE 3: FRICTION COEFFICIENT EVOLUTION VERSUS TEMPERATURE

There is a big difference in test results between ANP and CEA test results in term of frictions coefficient. In term of wear, results are similar (Table 1).

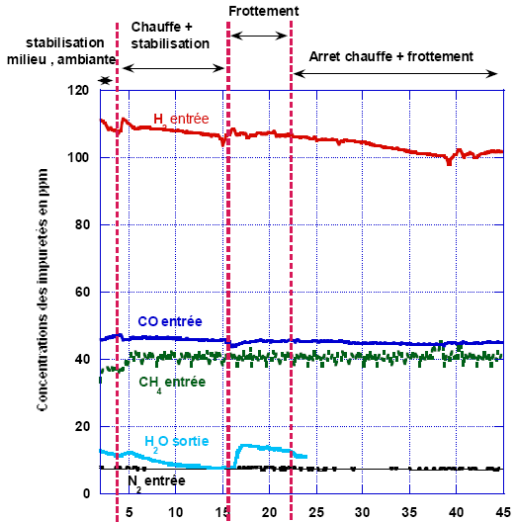
Differences in test devices lie in the way of applying normal load, and the management of impurities.

The requirement for the gas composition was:

Impurity	*Concentration in vpm*	*Partial pressure for 50 bar in µbar*	*Concentration in ppm for 3 bar*	*Concentration in ppm for 1 bar*
H_2O	< 0.1	< 5	2	5
CO	< 2	< 100	34	100
N_2	< 1	< 50	17	50
H_2	< 5	< 250	84	250
CH_4	< 1	< 50	17	50

For ANP tests:

Impurity	*Concentration in ppm for 1 bar*	*Concentration in ppm measured*
H_2O	< 5	Nm ; 13
CO	< 100	44 ; 44
N_2	< 50	6 ; 8
H_2	< 250	82 ; 110
CH_4	< 50	41 ; 40
CO_2		< 1
O_2		< 1



For CEA tests[1]:

Impurity	*Concentration in ppm for 3 bar*	*Concentration in ppm measured*
H_2O	< 2	Not measured
CO	< 34	17 to 155 ; 1100 to 2010 ; 1.5 to 11 ; 2 to 14 ; 8 to 49
N_2	< 17	133 to 165 ; 90 to 120 ; 25 to 35 ; 30 to 43 ; 130 to 160
H_2	< 84	Not measured
CH_4	< 17	Not measured
CO_2		218 to 376 ; 50 to 22 ; 30 to 110 ; 50 to 150 ;250 to 590
O_2		22 to 28 ; 25 to 42 ; 8 to 21 ; 12 to 28 ; 20 to 38

[1] The several ranges in concentration measured correspond to the evolution of impurity content for each test

These two tables show the difficulty to get a controlled medium. The level of impurities required is very tight and the tribometer has to be designed for the study of tribology in a controlled environment (no reactive surface in the hot zone except the samples, connection to a loop to manage impurities). Test weren't performed in the same conditions.

An additional test has been performed in ANP on a classical pin on disk tribometer (the same that was used for HRT-E tests). The gas used is issued from a bottle of pure He, quality 5.5.

The parameters are the same as test 10 performed by CEA (PCEA / 800H; 500°C; 4 MPa). The result is similar to CEA result (Figure 4).

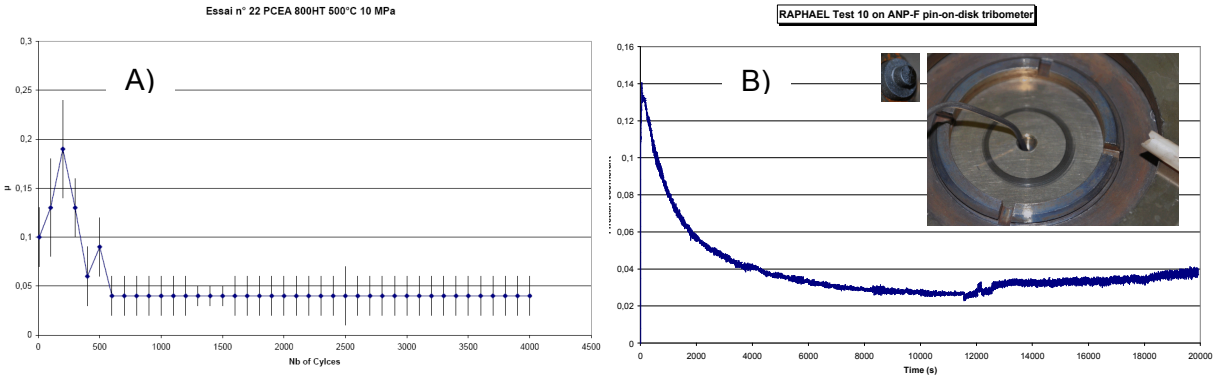


FIGURE 4: COMPARISON OF FRICTION COEFFICIENT VARIATION, PCEA / 800H, 500°C ; A) CEA 10 MPA ; B) ANP 4 MPA

The conclusion is that tests have been performed in a VHTR environment (helium + impurities) on two test benches in CEA and ANP-F. The major result is that wear is mild (Figure 5). There is no significant difference between PCEA and NBG-17 in like-on-like contact. When graphite rubs on 800H, in term of wear the order of magnitude is the same, but in term of friction coefficient, it's higher for NBG-17 than for PCEA. The structure of debris is function of temperature. At 1000°C, debris are relatively small, around 800°C, debris contain more plates and at 500°C, plates are larger.

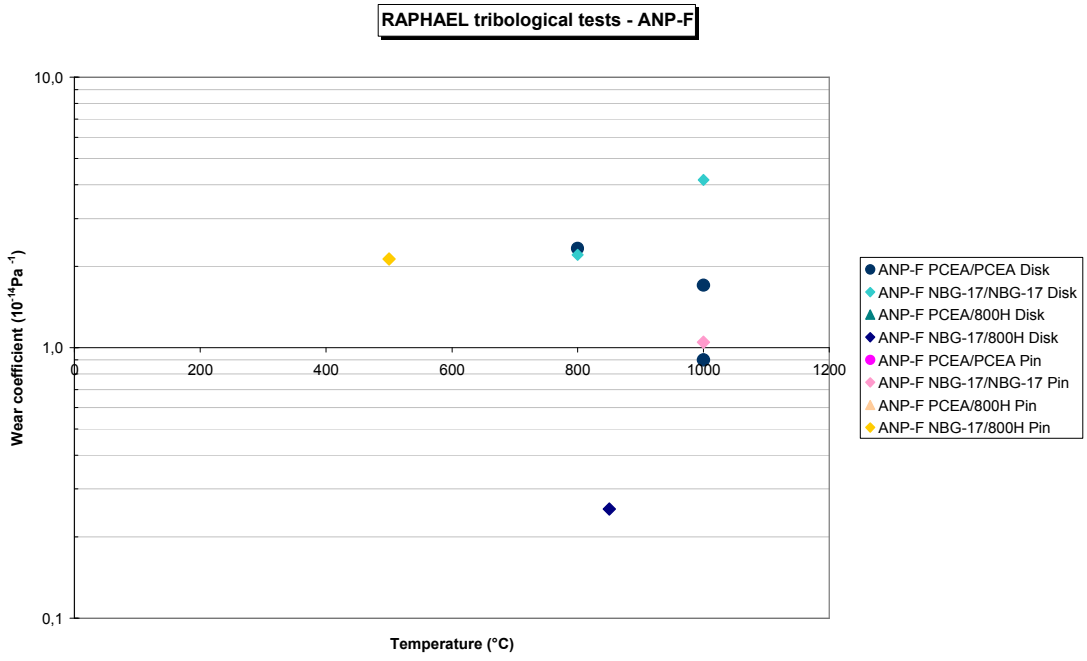


FIGURE 5: WEAR COEFFICIENTS FOR ANP-F TESTS

3. COMPARISON OF EXPERIMENTAL RESULTS AND FEEDBACK EXPERIENCE ON FORMER HTRS

It's difficult to compare results with feedback experience: graphite grades are new and there is no result above 800°C. That's why it was interesting to realize test in these conditions because there was a lack of data.

In table 4 from document [3], NNC part, at 700°C, Gilsocarbon on Gilsocarbon, pure He, the mean friction coefficient is between 0.3 and 0.4, and the maximal value can reach 0.8.

In a graphite / metal contact, for example Gilsocarbon on 316, the mean friction coefficient is between 0.25 and 0.3, and the maximal value is 0.4.

Other results are given in table 5 from the same document (Gilsocarbon like on like in pure He).

These results can just give us an order of magnitude. Materials and test conditions are different.

In term of wear, the levels measured are same as with Gilsocarbon at high levels of temperature (Specific wear rate < 5.10^{-14} $m^3/(N.m)$). This can be qualified of mild wear.

4. ANALYSIS OF THE APPLICATION OF THE RESULTS ON VHTR DESIGN: RECOMMENDATIONS

The major recommendations for VHTR design are:

- Generally to put sliding in cold temperature zones;
- To avoid adhesion between graphite and metal, it is recommended to use the couple of materials that gives the lowest friction coefficient (on 800H, PCEA presents lower friction coefficients);
- To limit the quantity of debris by limiting the wear (PCEA presents a bit lower specific wear rates);

5. CONCLUSION

New grades of graphite have been tested on two tribological devices in CEA Cadarache and in ANP-F Le Creusot (technical center): PCEA (from Graftech UCAR) and NBG-17 (from SGL Carbon GmbH)[2], in like-on-like or graphite / metal type of contact. The other parameters are the load and the temperature. The tests are realized in helium + impurities. During ANP-F tests, the level of impurities is managed with a helium loop connected to the tribometer. In CEA, a bottle of pure helium is used, but the tribometer wall materials degas when heated.

The main results are summarized here after:

Like-on-like:

- Mild wear;
- No significant difference between PCEA and NBG-17;
- Impact of gas composition: on ANP-F's test bench, friction coefficients are higher than on CEA's device. With the temperature, the evolution of Cf is low between 800 and 1000°C in CEA; while in ANP-F, Cf decreases when the temperature increases (from around 0.9 at 800°C to 0.5 / 0.6 at 1000°C).

Graphite / metal:

- Mild wear;
- The friction coefficient is lower in the case of PCEA/800H than NGB-17/800H (at 850°C, respectively 0.44 and 0.77, ANP-F test results);
- Large impact of gas composition: the results obtained in CEA show a low friction coefficient whatever the level of temperature (PCEA/800H, Cf 0.04 at 500 and 850°C), while results obtained in ANP-F are much higher and Cf increases with temperature (NBG-17/800H, Cf 0.69 at 500°C and 0.77 at 850°C).

PCEA presents a better behavior to tribological solicitations than NBG-17 (in regards of wear and friction).

	Manufacturer	*Grade*	*Coke*	*Process*	*Status*
Graphite 1	GrafTech UCAR	PCEA	Petroleum	Extrusion	Major
Graphite 2	SGL Carbon GmbH	NBG-17	Pitch	Vibro-moulded	Minor

[2]